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Three Regional Studies

Resources for the Future, Inc., Washington, DC

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TRENDS IN U.S. IRRIGATION: THREE REGIONAL STUDIES

by

Resources for the Future
Washington, D.C. 20036

Grant No. R8060236010

Project Officer

George W. Bailey
Environmental Research Laboratory
Athens, Georgia 30613

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Resources for the Future

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OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

Three separate reports, each dealing with irrigation in a different region of the United States are brought together in this volume. Although they are disparate in approach and level of effort, combined they provide a comprehensive view on the prospects for irrigated agriculture in the United States for the next several decades. The first study, "Western Irrigation: Its Past and Future Growth," assesses the role of irrigation in the 17 western states in producing the nation's farm output and the resource and environmental pressures affecting and stemming from western irrigation. The second study, "Growth and Prospects for Irrigation in the Eastern United States," provides a brief history of the growth of irrigated acreage by farm production region and an assessment of the prospects for increased irrigation in the Lake States and the Southeast. The third study, "The Economic Potential for the Expansion of Irrigation in the Mississippi Delta Region," focusses on a sample six-county area and employs benefit-cost analysis to estimate the potential number of acres that can be profitably irrigated under alternative product prices, input costs, management levels, and irrigation systems.

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FOREWORD

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Three separate reports, each dealing with irrigation in a different region of the United States are brought together in this volume. Although they are disparate in approach and level of effort, combined they provide a comprehensive view of the prospects for irrigated agriculture in the United States over the next several decades.

David W. Duttweiler
Director
Environmental Research Laboratory
Athens, Georgia

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ABSTRACT

Three separate reports, each dealing with irrigation in a different region of the United States are brought together in this volume. Although they are disparate in approach and level of effort, combined they provide a comprehensive view of the prospects for irrigated agriculture in the United States over the next several decades.

The first study, "Western Irrigation: Its Past and Future Growth" by Kenneth D. Frederick assesses the role of irrigation in the seventeen western states in producing the nation's farm output and the resource and environmental pressures affecting and stemming from western irrigation. Past trends in irrigated acreage, water supply conditions, water institutions, economic forces, and environmental factors are examined. Analysis of these factors is the basis for projecting changes in both the extent and the nature of irrigation and for drawing conclusions as to the need and means of encouraging a more efficient use of scarce water supplies in the West. Future expansion of western irrigation will be much more dependent on crop price levels than in the past, and acreage as well as water withdrawals will become increasingly poor indicators of irrigation's contribution to U.S. agriculture. In much of the West additional irrigated acreage is constrained by physical and institutional limits on developing new water supplies. Most of the acreage increases will be in the Northern Plains states, especially Nebraska. Rising water costs will encourage the search for and increase the profitability of water-saving investments. Since the problems of erosion, sedimentation, and water quality degradation associated with irrigation generally diminish as the application efficiency of water increases, these investments will have beneficial environmental impacts. While western irrigation is not likely to make the overall contribution to agricultural growth that it did when water was readily available at lower cost, irrigation will contribute to the growth of agricultural production for many more decades if the transition from water abundance to scarcity provides farmers with incentives for water conservation.

The second study, "Growth and Prospects for Irrigation in the Eastern United States" by James Hanson and James Pagano, provides a brief history of the growth of irrigated acreage by farm production region and an assessment of the prospects for increased irrigation in the Lake States and the Southeast. The most rapid growth will be irrigated corn and soybeans in the sandy areas of northwest Florida, southwest Georgia, central Wisconsin, central Minnesota, eastern Michigan, and northern Indiana.

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The third study, "The Economic Potential for the Expansion of Irrigation in the Mississippi Delta Region" by Robert N. Shulstad, Ralph D. May, Billy E. Herrington, and Jon M. Erstine focuses on a sample six-county area and employs benefit-cost analysis to estimate the potential number of acres that can be profitably irrigated under alternative product prices, input costs, management levels, and irrigation systems. Under nearly all scenarios examined, the results indicate at least 90 percent of the region's cropland can be profitably irrigated under crop rotations involving soybeans, rice, cotton, or wheat.

This report was submitted in fulfillment of Grant No. R8060236010 by Resources for the Future under the sponsorship of the U.S. Evnironmental Protection Agency. This report covers the period October 1978 to December 1980, and work was completed as of June 1981.

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PREFACE

As part of a research program to examine the resource and environmental implications of expanding agricultural production in the United States, Resources for the Future undertook two studies of irrigation, and contracted with the University of Arkansas for a third study. The two RFF studies are "Western Irrigation: Its Past and Future Growth" by Kenneth D. Frederick with assistance from James Hanson and "Growth and Prospects for Irrigation in the Eastern United States" by James Hanson and James Pagano. The University of Arkansas study is "The Economic Potential for the Expansion of Irrigation in the Mississippi Delta Region" by Robert N. Shulstad, Ralph D. May, Billey E. Herrington, and Jon M. Erstine. The three studies, which taken together represent a major effort to understand irrigation's past and future importance to agriculture in the United States, comprise this report to the Environmental Protection Agency.

The three studies are very disparate in approach, methodology, and level of effort. The differences among the studies reflect in part variations as to the importance of irrigation in the different regions of the country and in the research needed to understand the forces likely to affect irrigated agriculture in these regions. The scope and depth of the studies also were influenced by the relatively modest resources available for the research on irrigation.

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The seventeen western states were selected as the subject of a major research effort because this is the region where irrigation has the greatest impact on agricultural output, where rising water costs and limited supplies threaten to curtail irrigation in some areas, and where most of the nation's irrigated acreage is located. Furthermore, there is considerable debate and uncertainty as to both the importance of western irrigation to the nation's agriculture and the implications of rising energy and water costs for future changes in irrigation. The study assesses the role of western irrigation in producing the nation's farm output and the resource and environmental pressures affecting and stemming from western irrigation. Past trends in irrigated acreage, water supply conditions, water institutions, economic forces, and environmental factors are examined in some detail. The analysis of these factors provides the basis for projecting changes in both the extent and nature of western irrigation and for drawing some conclusions as to the importance of and means for encouraging a more efficient use of scarce water supplies.

The study of western irrigation is primarily a synthesis of data collected and research done elsewhere. Numerous micro-level studies done by others examine how farmers in specific locations of the West can be expected to respond to various factors such as changing water and energy costs. While these studies alone are of limited use for analyzing overall changes in western irrigation, they provide a rich literature which is drawn upon to analyze aggregate changes in western irrigation. The broad scope of the study of western irrigation provides insights as to the overall changes in western irrigation, but it does not permit analysis as to how individual

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farmers or irrigation districts might be affected by changes in water costs, water institutions, or other factors influencing the profitability of irrigation.

The study of eastern irrigation (outside the Mississippi Delta) represents a much more modest research effort. This paper provides a brief history of the growth of irrigated acreage by farm production region and an assessment of the prospects for increased irrigation in the Lake States and the Southeast. The Delta region was not considered in this analysis since it was studied separately by a group at the University of Arkansas; the Northeast, Appalachian, and Corn Belt regions were omitted because the prospects for irrigation in these regions were considered too small to warrant close attention in view of the limited resources available for the overall research.

A very different methodological approach is utilized in the study of the Mississippi Delta region. The Delta study focuses on a sample six-county area and uses cost-benefit analysis to estimate the potential number of acres of a particular land and soil group that can be profitably irrigated under alternative product prices, input costs, management levels, and irrigation systems. The Delta region was singled out for special consideration since recent irrigation investments and potential for expansion suggested supplemental irrigation of rice and soybeans and of wheat in rotation with soybeans might become a factor of some importance to the future growth of U.S. agriculture. The micro-level cost-benefit approach was determined to be the most appropriate means of estimating the economic potential of irrigation in the region.

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Considered together, the three studies indicate irrigation has become an increasingly important factor in U.S. agriculture over the last several decades. Its overall role in agricultural expansion over the next two to three decades, however, is clouded by pressures on western water resources and high energy costs which will slow the growth of irrigated acreage in the seventeen western states. While further net expansion of irrigated acreage is likely in the West despite the negative factors on its growth, acreage will become an increasingly inadequate measure of irrigation's impact on agricultural production as investment, research, and farm management practices are increasingly directed to increasing the returns to water and the yield to irrigated farming.

The study of the Mississippi Delta region was very bullish on the prospects for expanding irrigated acreage. Under sixteen of the twenty-four situations examined, it was profitable to irrigate 15.5 million acres of cropland. Even under the most unfavorable alternative, it was profitable to irrigate 9.4 million acres in the Delta. At least 90 percent of the region's cropland could be profitably irrigated under all but two of the twenty-four scenarios examined.

In the rest of the East the expansion of irrigation will be fastest in areas with sandy soils where irrigation can have the greatest impact on yields. In particular, northwest Florida and southwest Georgia and the sandy areas in central Minnesota, central Wisconsin, eastern Michigan, and northern Indiana likely will experience relatively rapid growth of irrigation. Corn and soybeans should be the principal irrigated crops in these areas. In the rest of the East, irrigation largely will be limited, as it

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is now, to use on high-value, specialty crops grown for relatively narrow markets.

The most general conclusion suggested by the three studies is that while the West will continue dominant in total irrigated acreage, the East, in particular the Mississippi Delta, will increase in relative importance. This is consistent with certain emerging regional patterns of resource demand and supply: (1) increasing scarcity of water in the West reflecting higher energy costs of pumping groundwater and rising opportunity costs in non-agricultural uses of water; (2) the relatively abundant supply of water in the East; (3) increasing scarcity of land in the East reflecting rising demand for cropland to produce feedgrains and soybeans; (4) development of technologies, particularly sprinkler irrigation, permitting economical irrigation of moderately rolling lands not previously feasible for irrigation. These resource patterns are deep-rooted. Taken together they portend the end of the dominance of the West in the growth of irrigation. The sunbelt states of the West may continue to lead national economic expansion but irrigation will run counter to that trend.

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WESTERN IRRIGATION:

ITS PAST AND FUTURE GROWTH

by
Kenneth D. Frederick
Resources for the Future
Washington, D.C. 20036

With assistance of
James C. Hanson

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James Hanson, whose assistance is acknowledged on the title page, spent about twenty months at RFF working on irrigation research. In addition to his contribution to the present study, he was the principal author of the report on eastern irrigation which is included as part of this volume. On the western irrigation study, Hanson helped collect, organize, and analyze much of the data and source materials and he wrote early drafts of much of sections 4 and 5. However, there have been major revisions in all components of the study since Hanson's departure from RFF, and he has not had an opportunity to comment on the final version of the manuscript. Thus, it would be inappropriate to hold him responsible for any remaining errors.

James Pagano, who served as a research assistant for this study, also merits special thanks. In addition to bringing great diligence and patience to performing some of the more tedious tasks associated with the project, he contributed many useful ideas and insights, especially to section 5. Maybelle Frashure has patiently and ably typed numerous drafts of this manuscript.

On Febraury 26, 1980 a workshop was held in Denver, Colorado to discuss this research project. The study has benefited from the experts, representing a variety of disciplines and considerable experience with irrigation and water issues, who generously contributed their time to participate in that session.

Financial support for the research on resource and environmental problems of U.S. agriculture was provided by the Rockefeller Foundation, the Environmental Protection Agency through their Rural Lands Research Program, Environmental Research Laboratory, Athens, Georgia, and Resources for the Future. This study of irrigation benefited from all these funding sources.

SECTION 1

INTRODUCTION

BACKGROUND TO THIS STUDY

Agricultural development has been one of the United States' great economic success stories. Total crop production rose 72 percent from 1950 to 1978 while total cropland use declined by 1 percent and farm labor for crop production declined by 65 percent. Underlying these changes was a 65 percent rise in total farm productivity.[1]

If we could be certain agricultural productivity would continue to rise at an average annual rate of nearly 1.9 percent, there would be little cause for concern as to the ability of U.S. farmers and the adequacy of farmland to meet future crop needs without sharp price increases. Furthermore, continued productivity growth would make the environmental impacts of agricultural expansion more manageable. While rapid productivity increases do not necessarily reduce (indeed, the inputs associated with the new technologies may generate additional) environmental pressures, they do increase the options for dealing with these problems.

Unfortunately, there are reasons to expect that past productivity trends will not continue and that meeting future demands for food and fiber may result in higher economic and environmental costs per unit. The performance of the agricultural sector since the early 1970s provides some basis for concern. The annual rates of productivity and yield increases from 1971 to 1978 were less than one-half the respective rates achieved over the prior twenty-one years.[1] Other sources of concern include rising energy and fertilizer prices; mounting evidence that additions to the cropland base will be less productive, more erodable, or more expensive to develop than the lands previously used; increasing water costs; and a growing belief that the major yield gains from the technologies that have revolutionized U.S. agriculture in recent decades have been achieved.

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[1] Calculated from data in Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, Changes in Farm Production and Efficiency, 1978, Statistical Bulletin No. 628, January 1980.

To improve our understanding of these factors, Resources for the Future (RFF) undertook a research program to study the resource and environmental issues associated with expanding agricultural production in the United States. This research effort includes assessing (1) the quantities of land, water, fertilizers, and pesticides U.S. farmers would demand in response to high demand projections; (2) the economic and environmental costs of mobilizing resources on this scale; (3) the past and future role of irrigation, taking into account the impacts of rising water costs as well as the technologies available for adapting to higher costs; (4) the costs, productivity, and environmental consequences of alternative tillage, pest management and fertilizer technologies; (5) the social and economic obstacles to the adoption of environmentally beneficial technologies; and (6) the alternative policies and institutions appropriate for minimizing the combined economic and environmental costs of agricultural production. The following study of irrigation in the West is a part of this overall research program.

IRRIGATION OVERVIEW AND MAJOR ISSUES

Although the data do not exist to quantify with precision irrigation's contribution to overall agricultural growth, there are reasons to believe the impact has been sizable in recent decades. Irrigated acreage tripled from

---

[1] Ibid.

1940 to 1977 and doubled from 1950 to 1977, periods of virtually no change in total cropland use. Average yields are greater on irrigated farms, and within the arid and semiarid areas technological change has been higher on irrigated than on nonirrigated farms.[1] Currently irrigation accounts for nearly one-seventh of the nation's cropland and more than one-fourth of the value of the nation's crops.[2]

Irrigation is particularly important in the western United States, especially those areas where rainfall is either insufficient or too unreliable to support a highly productive agriculture. About 83 percent of the nation's irrigated acreage is in the seventeen western states where irrigation accounts for nearly one-fourth of the cropland and more than one-half of the crop value. But even in more humid areas, irrigation can increase output by improving control over water, protecting against drought, facilitating double cropping, and encouraging the use of complementary inputs such as agricultural chemicals and improved seed and the planting of higher value crops.

The availability of relatively inexpensive water spurred the growth of irrigated agriculture. Water was initially treated as a free good in the West. The original users not only were allowed to use the water without charge but were granted the rights to use similar quantities in perpetuity.

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[1] Economic Research Service, U.S. Department of Agriculture, Measuring the Effect of Irrigation on the Rate of Technological Change, Agricultural Economic Report no. 125, November 1967, p. iv.

[2] Data differentiating between the value of production on irrigated and nonirrigated lands are not available for 1977. Dallas Lea, using a combination of data from the 1969 Census of Agriculture and 1971-73 estimates of the Statistical Reporting Service, estimated that 27 percent of the value of U.S. crop production was produced on irrigated lands. (See Lea, "Irrigated Agriculture: Past Trends, Present State, and Problems of Future Expansion," second review draft, August 1977, table 2. Lea is with the Economics and Statistics Service of the U.S. Department of Agriculture.

The only costs to the users were those associated with capturing and transporting water from its source to point of use. Until recently low energy prices helped keep down the costs of transporting water, and farmers accounting for about one-fifth of the West's irrigated acreage continue to benefit from large federal subsidies on irrigation projects.

Current demands on (and sometimes even the rights to) western surface waters commonly exceed available supplies, while extensive groundwater mining (that is, withdrawing groundwater faster than it is replenished) has placed current users in conflict with potential future users. Western water use and development have become issues of growing national concern and debate--often pitting one region of the country against another or western farmers, conservationists, and developers against each other. Development of western energy resources, expansion of western urban and rural areas, preservation of the West's natural resources, continuation of federal subsidies for western water development, Indian water rights, as well as the role of western irrigation in U.S. agriculture are issues in the resolution of these conflicts.

Irrigation is the activity most acutely affected by the elimination of inexpensive water in the West. Agriculture, which accounts for about 88 percent of western water consumption, is not only the largest but also the marginal user of western water. That is, irrigators would be least able to compete for scarce supplies if water were allocated through a market mechanism. The prospect of sharply higher water costs not only threatens expansion but also endangers the viability of many current irrigators. On the other hand, the forces affecting the role of irrigated agriculture in the West are not all negative. Developments which will tend to counter the impact of rising water costs include more efficient irrigation systems, new crop varieties requiring less water, and improved knowledge of the relation between plant growth and water stress. Such developments will enable less water to be applied with little or no decline in yields. Furthermore, most water is not allocated through markets, and farmers who have been irrigating with surface water enjoy a very favorable position in the future allocation of western surface waters. Irrigators possess most of the senior rights to these waters, many are insulated from the pressures pushing up water costs, and in most states a myriad of laws and institutions make it difficult to transfer these rights to nonagricultural uses.

Less may be known about the impact of irrigation on the overall performance of U.S. agriculture than is known about the impact of any of the other principal inputs. One manifestation of our ignorance is the widely divergent views on irrigation's importance to U.S. agriculture and the implications of a major reduction in irrigated acreage. On one extreme research done at Iowa State in the 1970s downplays the importance of irrigation. For example, projections to the year 2000 suggest that if "allowed to be distributed in terms of competitive conditions and interregional comparative advantage (no supply control), the nation's domestic and export food demands could be met more economically by using less water in agriculture and by a wide redistribution of crop acreage."[1]

Not surprisingly, this view is not shared by many, especially those whose livelihood depends on the output of irrigated lands. For instance, great national and global benefits in the form of abundant and cheap food and fiber have been attributed to the spread of irrigation within the High Plains; dire warnings have been raised as to the consequences of allowing that area to revert back to dryland farming.[1] Self-interest undoubtedly underlies some of the concern for the national implications of having irrigated acreage decline in areas where groundwater stocks are being depleted. But the disparity of views persists in part because of the inconsistency among the data describing the extent of irrigation, the lack of reliable data describing the impact of irrigation on yields and production, and the absence of analysis differentiating between the roles of irrigated and dryland farming.

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[1] Earl O. Heady, "U.S. Supply Situation for Food and Fiber and the Role of Irrigated Agriculture," an unpublished paper prepared for Texas A&M Conference, March 25-26, 1976.

OBJECTIVES, APPROACH, AND ORGANIZATION OF THIS STUDY

Although there is dispute as to just how important irrigation is to our agriculture, it is clear that its contribution to U.S. production has grown markedly in recent decades and that irrigation has important impacts on the land as well as the water required to produce agricultural output. Existing studies, however, shed little light on the role of irrigation in national agricultural production. Studies and models taking an overall view of U.S. agriculture either ignore differences between irrigated and dryland production or handle them in a manner with limited use for analyzing past, current, and future impacts of irrigation.[2] On the other hand, studies focusing on irrigation and the forces affecting its growth have been farm or locality specific. There is no lack of detailed micro-oriented studies, but taken alone they also are of limited use for analyzing the overall role of irrigation on U.S. agriculture.

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[1] For example, see A. L. Black's article in "High Plains Ogallala Study" in Frank C. Baird, editor, The Multi-Faceted Water Crisis of West Texas, Proceedings of a symposium held November 8-9, 1978, Lubbock, Texas, p. 147.

[2] For example, consider the shortcomings of the two principal models of U.S. agriculture from the perspective of analyzing the role of irrigation. Irrigation was not a principal concern in developing the National-Interregional Agricultural Projections (NIRAP) system although the model does provide estimates of irrigated crop production. Its insights into the role of irrigation are limited by reliance on data grossly understating recent irrigation and by the absence of any analysis of the factors likely to affect future levels. The other major model, developed at Iowa State, is designed to analyze least-cost methods of producing alternative levels of output. Both current and future levels of irrigation projected by the model are well below recent actual levels. There is some controversy as to whether these results indicate

The present study is a systematic attempt to assess both the current and the future role of western irrigation in producing the nation's farm output and the resource and environmental pressures affecting and stemming from western irrigation. Past trends, water supply conditions, water institutions, economic forces, and environmental factors are examined for their impacts on the course of western irrigation over the next two to three decades. The influence of these institutions and economic forces on resource use efficiency and environmental considerations also are considered along with the broad policy implications of the analysis.

The study focuses on the seventeen western states largely because this is the region where irrigation has the greatest impact on agricultural output, where rising water costs and limited supplies threaten to curtail irrigation, and where most of the nation's irrigated acreage, especially acreage devoted to corn, sorghum, wheat, and cotton (crops of principal interest in the broader RFF study) presently is located. Separate studies of irrigation in the Mississippi Delta region and in the eastern states were undertaken as

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(footnote 2 continued
that irrigation has been inappropriately handled in the model or that many irrigators are high-cost producers who would be eliminated under any socially efficient allocation of farm resources. But in either case, the model does not provide a good means for analyzing current or future irrigation levels. (Chapter 7 examines in more detail the limitations of these models for analyzing irrigation. The discussion of these models indicates their shortcomings as tools for fulfilling the objectives of this study; the comments should not be interpreted as general criticisms of the modeling efforts which have different objectives than those of this study.)

part of RFF's program of research on the resource and environmental impacts of U.S. agriculture.[1]

This study is primarily a synthesis of work done elsewhere. This approach to the subject in part was necessitated by the broad scope of the research and the limited resources available to it. But the approach also reflects the author's judgment that a synthesis offered the most promising way of assessing the role of irrigation and its future course. No effort has been made to generate original data and the analysis is necessarily cast at a high level of generality. The analysis relies on existing data sources, generally those gathered and published by the federal or state governments as part of their systematic efforts to develop statistics on agricultural and water developments. However, major inconsistencies among the various sources of irrigation data necessitated taking a close look at the data and how they were obtained. This examination involved both a comparison of alternative sources as well as an investigation of the methods used to collect the data. The results of the data assessment are included as an appendix to this study.

Each of the next five sections examines in some depth one of the principal factors affecting the growth and performance of irrigated agriculture in the West. No formal models have been developed to relate the various factors affecting irrigation. These five sections are primarily a synthesis of a large body of data and research supplemented by numerous interviews with agricultural and water experts in the West. Where the literature was inadequate for the purposes of this study--such as determining the contribution of irrigation to past production and yield increases of principal crops--original research was undertaken. The methodology employed in these instances is explained in the text and accompanying notes.

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[1] The Mississippi Delta study was done by a team at the University of Arkansas. See Robert N. Shulstad, Ralph D. May, Billy E. Herrington, and Jon M. Erstine, "The Economic Potential for the Expansion of Irrigation in the Mississippi Delta Region," Final Report prepared for Resources for the Future, June 30, 1980. The report on eastern irrigation is by James Hanson and James Pagano and entitled, "Growth and Prospects for Irrigation in the Eastern United States," preliminary, September 1980.

By focusing the study on the overall role of western irrigation, variations among and within different regions often are obscured. Countless factors such as soil type, the cost, availability, and quality of water, the availability and cost of energy, climate, and management capability are crucial determinants of the crops grown, the irrigation techniques used and the physical and monetary returns gained. While the impacts of many of these factors on irrigation are examined, there is nothing in the analysis to suggest how an individual farmer will fare or how the combination of these factors determine the potential of irrigation in a region. On the other hand, an effort is made to isolate and analyze the principal factors affecting the overall level and nature of western irrigation. And for some purposes the analysis is regionalized to farm production regions or more homogeneous irrigation areas. But there is no systematic attempt to describe either the conditions affecting irrigation in any one region or the full range of conditions affecting western irrigation.

Section 2 examines the current role of western irrigation--that is, the acreage irrigated and its location, the crops grown, the yields, and the importance to the national production of major crops--and how we got there. Past trends and the changes in those trends as well as the impacts of irrigation on past changes in the production and yields of corn, sorghum, wheat, and cotton are analyzed. As noted above, determining current and past levels of irrigation proved to be much more difficult than anticipated and required analysis of the data sources. The detailed discussion of the data has been relegated to an appendix.

Section 3 examines the supply and demand for western water. The sources of water for the past expansion of irrigation, the adequacy of ground and surface water supplies for maintaining and expanding irrigation, the growing competition for western water, and the possibilities for augmenting supplies all are considered.

Section 4 examines the institutions including the laws and water organizations affecting the allocation of western water. Institutional constraints on transferring water among alternative uses and impacts on farmer's incentives to use water efficiently are considered.

Section 5 examines the impacts of rising energy costs and water scarcity on the profitability of irrigation under a variety of circumstances. The possibilities for reducing water costs through alternative irrigation technologies and water management practices also are assessed. The impacts of higher water and energy costs and alternative crop prices on the relative profitability of irrigated and dryland farming in the semiarid West are considered.

Section 6 examines the environmental impacts of irrigated agriculture. First, the nature and extent of the environmental impacts are described and then alternative ways to manage these problems, federal efforts to control irrigation runoff, and several other approaches to managing the environmental impacts of irrigation are examined.

Section 7 starts with a summary of the principal conclusions of the previous five sections. This is followed by an evaluation of projections of irrigated acreage which have been made as parts of several major water or agricultural studies. Then drawing on the prior analysis, alternative projections of irrigated acreage and anticipated changes in the nature of irrigated agriculture are considered. Finally, policy implications of the overall study are examined.

SECTION 2

THE ROLE OF IRRIGATION

INTRODUCTION

Regretably, the role of irrigation in U.S. agriculture looks different depending on the data sources utilized. For example, the 1974 Census of Agriculture shows only 41.2 million acres irrigated in the fifty states and 36.6 million in the seventeen western states. In contrast, the 1977 National Resources Inventory (NRI) estimates irrigated acreage at 60.7 million in the fifty states and 50.2 million in the seventeen western states. As explained in the appendix, neither definitional differences nor the three years separating the census and the NRI can explain away all or even most of these differences. Yet, the agricultural censuses and the inventory data of the Soil Conservation Service (SCS) (the 1977 NRI is the most recent) are the two principal primary data sources providing estimates of irrigated acreage in every state. In view of these problems, a detailed analysis of the irrigation data was essential before attempting to describe current and historical irrigation levels. The appendix presents the analysis of the data; this introduction summarizes the conclusions of that analysis and indicates how the data are used in this study.[1]

Principal conclusions of the examination of the census, NRI, and other sources of irrigation data included in the appendix of this study are (a) the 1974 and 1969 agricultural censuses grossly understate the level of irrigation and (b) the statistical techniques combined with the reliance on trained personnel to gather and independently verify the data suggest that 1977 NRI and 1967 Conservation Needs Inventory (CNI) estimates, especially on the national and regional levels, are the most reliable irrigation data available for all states. Comparisons of these primary data sources with independently gathered irrigation data available for a few states support these conclusions.

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[1] When this study was started and the first draft completed, 1974 was the most recent agricultural census for which data were available. Preliminary summary data from the 1978 agricultural census have since become available. As noted in the appendix, these data as well as some recent comments by Bureau of the Census officials regarding problems with the 1969 and 1974 censuses support some of the principal conclusions of the analysis presented in the appendix to this study. The 1978 agricultural census has not been utilized in this analysis of irrigation; indeed, the detailed data are not yet available to do so.

Unfortunately, there are some major shortcomings with the SCS survey data for assessing current levels of, and past changes in, irrigation. The surveys were designed for identifying cropping patterns with soil types and related conservation problems; irrigation was not a primary concern of the surveys. Since irrigated acreage is defined in the 1977 NRI survey to include lands where water is supplied as part of a cropping system as well as acreage actually irrigated, the estimates overstate acreage irrigated in the survey years. For example, the 1977 NRI survey includes lands irrigated in the survey year or in two of the previous four years. The resulting overestimate probably is not large in the western states, and in view of the alternatives, this shortcoming was not important enough to alter the conclusion that the NRI data offer the most reliable source of recent western irrigation levels. But the usefulness of the SCS irrigation estimates also is limited by data for only two years (1967 and 1977) and the absence of data by crop or for regions divided along non-state boundaries.

In view of the data deficiencies, estimates from a number of sources have been used to analyze current and historical irrigation levels. The 1977 NRI data are used to examine recent irrigated acreage by state and farm production region. Where greater regional detail or data for individual crops or longer time periods are required, SCS survey data are supplemented with data from the agricultural censuses, state surveys, or other sources. In such cases the biases introduced by use of the various data sources and the manipulations made upon them are examined. However, to prevent undue disruption to the flow of the analysis, much of the discussion of the data has been relegated to the appendix.

RECENT ROLE OF IRRIGATION

Nationally irrigation accounted for nearly 14 percent of total cropland and 11 percent of combined cropland and pasture use in 1977. Of the estimated 60.7 million irrigated acres, 55.7 million were cropland and 5.0 million were pasture (see table 2-1). These lands produced more than one-fourth of the value of the nation's crops.

Nearly 83 percent of the nation's irrigated acreage was in the seventeen western states, where about 23 percent of the cropland and more than one-half of the value of crop production was irrigated. Within the West dependence on irrigation was highest in the more arid areas. Irrigation in the Pacific and Mountain regions, for example, accounted for 51 and 36 percent respectively of cropland use. In the Southern and Northern Plains, which have extensive areas favorable for dryland agriculture, only 20 and 11 percent of the respective cropland was irrigated.[1]

The only crop disaggregation available in the NRI data are for groups such as row and close-grown crops. Table 2-2 indicates the irrigated and dryland acreage planted to five crop categories. One-half of the 46.4 million irrigated cropland acres in the West were in row crops, principally corn, sorghum, and

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[1] In view of the sampling techniques utilized in the National Resources Inventory, these data are more reliable when aggregated by farm production region than they are at the state level. The U.S. Department of Agriculture's farm production regions are identified in the notes to table 2-1. Since the farm production regions are large with considerable heterogeneity in the conditions affecting irrigation, subsequent analysis also will use other regional breakdowns both to accommodate alternative data sources and to shed further light on the factors affecting past and future growth of irrigation.

Table 2-1. 1977 Irrigated and Dryland Agricultural Land Use by Farm Production Region

(millions of acres)

Farm Production Region[1]	Irrigation			Dryland			Total		
	Cropland	Pasture	Total	Cropland	Pasture	Total	Cropland	Pasture	Total
Northern Plains	10.6	0.1	10.7	83.9	9.4	93.3	94.6	9.5	104.1
Southern Plains	8.6	0.4	9.0	33.6	27.1	60.7	42.2	27.5	69.7
Mountain	15.2	2.0	17.2	27.1	5.5	32.6	42.2	7.4	49.6
Pacific	11.9	1.4	13.3	11.2	2.8	14.0	23.2	4.1	27.3
17 Western states	46.4	3.9	50.2	155.8	44.7	200.5	202.2	48.5	250.7
Northeast	0.4	0	0.4	16.5	5.8	22.3	16.9	5.8	22.7
Appalachian	0.4	0	0.4	20.4	18.5	38.9	20.8	18.5	39.3
Cornbelt	1.1	0	1.1	88.8	25.2	114.0	89.9	25.2	115.1
Lake States	1.0	0	1.0	43.2	6.9	50.1	44.1	6.9	51.0
Southeast	2.4	1.0	3.4	15.1	13.1	28.2	17.5	14.1	31.6
Delta States	4.0	0.1	4.1	17.2	12.6	29.8	21.2	12.7	33.9
31 Eastern states	9.3	1.1	10.4	201.2	82.1	283.3	210.4	83.2	293.6
National Total	55.7	5.0	60.7	357.2	127.8	486.1	412.9	132.7	546.9

Source: U.S. Department of Agriculture, Soil Conservation Service, "Basic Statistics: 1977 National Resources Inventory (NRI)," Revised February 1980, tables 3a, 4a.

Minor differences in totals are due to rounding.

[1] These are the U.S. Department of Agriculture's farm production regions. In the West these regions are defined as follows: Northern Plains includes Kansas, Nebraska, North Dakota, and South Dakota; Southern Plains includes Texas and Oklahoma; Mountain includes Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming; Pacific includes California, Oregon, and Washington.

Table 2-2. 1977 Western Irrigated and Dryland Cropland Use by Crop Group and Farm Production Regions

(thousands of acres)

	Row Crops	Close-Grown Crops	Rotation Hay and Pasture	Native hay and Occasionally Improved Hay	Orchards, Vine-yards and Bush Fruit	Total Cropland
Northern Plains						
Irrigated	8,651	925	692	362	0	10,630
Dryland	18,059	40,013	5,387	6,375	15	83,944
Total	26,710	40,938	6,079	6,737	15	94,574
Southern Plains						
Irrigated	5,936	2,352	33	286	32	8,639
Dryland	13,906	15,784	802	1,127	152	33,583
Total	19,842	18,136	835	1,413	184	42,222
Mountain						
Irrigated	4,114	3,313	2,300	5,287	147	15,161
Dryland	964	14,026	383	1,595	0	27,063
Total	5,078	17,339	2,683	6,882	147	42,224
Pacific						
Irrigated	4,467	2,750	1,120	1,358	2,239	11,934
Dryland	134	5,558	499	506	184	11,238
Total	4,601	8,308	1,619	1,864	2,423	23,172
Western States						
Irrigated	23,168	9,340	4,145	7,293	2,418	46,364
Dryland	33,063	75,381	7,071	9,603	351	155,828
Total	56,231	84,721	11,216	16,896	2,769	202,192

Source: U.S. Department of Agriculture, Soil Conservation Service, "Basic Statistics: 1977 National Resources Inventory (NRI)," Revised February 1980, table 3.

cotton. Close-grown crops, primarily wheat and other small grains, accounted for 20 percent, various forms of hay and pasture for 9 percent, and orchards, vineyards, and bush fruit for 5 percent of the irrigated cropland. Yet, irrigated exceeded dryland acreage only for the category of orchards, vineyards, and bush fruit. Only 41 percent of the row crops, 11 percent of the close grown crops, and 41 percent of the various forms of hay and cropland pasture were irrigated.

There were large variations in the relative importance of the crop groups among the farm production regions. Row crops occupied more than 80 percent of the irrigated cropland in the Northern Plains, 69 percent in the Southern Plains, and between 27 and 37 percent in the other two regions. Hay and pasture occupied 50 percent of the irrigated cropland in the Mountain region and 21 percent in the Pacific region but were relatively unimportant in the other two regions. Orchards, vineyards, and bush fruit were important only in the Pacific region where they accounted for 19 percent of irrigated cropland.

PAST GROWTH OF IRRIGATED ACREAGE

1967 to 1977

Western irrigation expanded by nearly 9 million acres or 21 percent from 1967 to 1977 according to SCS survey data (see table 2-3). Nearly two-thirds of the expansion was in the Northern Plains where irrigation grew 7.8 percent per annum or 111 percent over the decade. More specifically, the expansion was concentrated in Nebraska (up 3.7 million acres) and Kansas (up 1.6 million acres) which together accounted for 61 percent of the total increase in western irrigation.

Irrigation in the rest of the West grew only 0.9 percent per annum over this decade. In the Southern Plains and Mountain regions, which combined accounted for 60 percent of western irrigation in 1967, irrigated acreage

Table 2-3. 1967 Irrigation and the Growth of Irrigated Acreage from 1967 to 1977 by Farm Production Region.

Region	1967 Irrigation (thousands of acres)	Change in acres irrigated, 1967-77 (thousands of acres)	Change in acres irrigated, 1967-77 (percentages)	Regional increase in irrigation as a percent of the increase in the West 1967-77
Northern Plains	5,088	5,665	111	65
Southern Plains	9,138	- 99	- 1	- 1
Mountain	15,916	1,200	8	14
Pacific	11,346	1,982	17	23
17 Western States	41,488	8,748	21	100

Source: Calculated from the 1967 Conservation Needs Inventory (CNI) and the 1977 NRI data references in table A-1.

rose only 4 percent over the decade. Growth in the Pacific region was close to the average rate for the West, but underlying the 21 percent regional increase was a 39 percent rise for Washington and Oregon combined and only a 9 percent rise in California. Thus, the Northern Plains and the Pacific Northwest, which together accounted for less than 20 percent of 1967 western irrigation, contributed 79 percent of the growth during the subsequent decade.

The expansion of western irrigation is particularly striking when contrasted with the change in nonirrigated cropland (see table 2-4). The decline in dryland acreage exceeded the rise in irrigated cropland from 1967 to 1977 in each of the western farm production regions. For the West as a whole, total cropland use declined 4.5 percent or nearly 9.5 million acres over the decade. As a result of these trends, the proportion of cropland under irrigation rose significantly in all four of the West's farm production regions, even in the Southern Plains which experienced a slight decline in irrigated acreage. For the seventeen western states as a whole, irrigated cropland rose from 18 to 23 percent of total cropland.

Table 2-4. Comparison of Changes in Irrigated and Nonirrigated Cropland Use, 1967 to 1977, by Farm Production Region

Region	Change in cropland use 1967-1977 (millions of acres)		Irrigated Cropland as a percent of total cropland	
	Irrigated	Dryland	1967	1977
Northern Plains	5.5	-6.7	5	11
Southern Plains	-0.2	-6.2	18	20
Mountain	1.5	-1.9	32	36
Pacific	1.0	-2.5	44	51
Western States	7.9	-17.3	18	23

Source: Calculated from 1967 CNI and 1977 NRI data referenced in table A-1.

1945 to 1974

A longer-term view of the expansion of irrigation using census data is presented in table 2-5. These data indicate a nearly continuous decline in both the annual rate of growth as well as the absolute growth in the number

Table 2-5. Growth of Irrigated Acreage in the West, 1945-1974

	Millions of acres irrigated	Change in acres irrigated[a]	% change in acres irrigated	Average annual growth of acres irrigated (in percent)
1945	19.4			
		4.8	25	4.5
1950	24.3			
		2.7	11	2.7
1954	27.0			
		3.9	14	2.7
1959	30.7			
		2.5	8	1.6
1964	33.2			
		1.6	5	0.9
1969	34.8			
		1.9	5	1.1
1974	36.6			

[a] Minor inconsistencies are due to rounding.

Source: Census of Agriculture, various years.

of acres irrigated in the West from 1945 to 1974. For example, the 4.5 percent per annum growth of irrigated acreage and the average annual addition of nearly 1 million irrigated acres achieved from 1945 to 1950 were considerably higher than the growth achieved in any subsequent period. In contrast, irrigation grew only 1.1 percent per annum for an average of less than 400,000 acres per year from 1969 to 1974 according to census data.

While the rate of growth of irrigated acreage probably has declined from the rates achieved from 1945 to 1959, the changes implied by the 1967 CNI and the 1977 NRI data raise questions as to whether or not the absolute growth of irrigated acreage has actually declined. As noted earlier, the SCS sources show an 8.7 million acre increase or nearly a 2 percent annual growth rate over the ten years in the seventeen western states compared to the 3.4 million acre ten-year expansion implied by the 1964 and 1974 agricultural censuses. For reasons noted above and in the appendix, the higher increase is probably much closer to actual growth.

Intertemporal irrigation changes from 1945 to 1974 for the various farm production regions are indicated in table 2-6. Over the entire twenty-nine year period, the census data show the Northern and Southern Plains each accounting for about one-third of the overall increase in western irrigation. Although more than half of all the acres irrigated were in the Mountain region in 1945, these states contributed only 12 percent of the West's growth. The remaining 23 percent of the growth was in the Pacific region.

The centers of irrigation growth have changed markedly over time. From 1945-54 growth was concentrated in the Southern Plains and Pacific regions. Indeed, Texas alone accounted for 45 percent and California for 28 percent of the total irrigation growth over this period. In contrast, these two leading irrigation states accounted for only 4 and 6 percent respectively of the growth from 1964 to 1974.

In terms of additions to irrigated acres, growth during the 1954-64 decade was the most evenly distributed among the four production regions. No region accounted for more than 30 or less than 17 percent of the growth of western irrigation. Variations in annual growth rates, however, ranged from 1.1 percent in the Pacific to 7.5 percent in the Northern Plains, the only region where irrigation grew at consistently high rates in each decade. Starting from a low base in 1945 (only 4 percent of western irrigation), the Northern Plains contribution to the growth of irrigation has increased markedly, and over the 1964-74 decade reached 83 percent according to census data.

As noted earlier, the SCS survey data show significantly more acreage irrigated than the census data in all production regions. Furthermore, the SCS data indicate an increase of 8.7 million acres irrigated in the West from 1967 to 1977 (see table 2-3) compared to the 3.4 million acre increase between the 1964 and 1974 censuses (see table 2-6). But in terms of the relative growth of irrigation among the farm production regions, the major difference implied by these alternative sources is for the Mountain region. The census data show irrigation in this region increasing at only 0.6 percent per year from 1945 to 1974 and declining over the last decade of this period. In contrast, the CNI and NRI show an increase of 1.2 million irrigated acres in the Mountain region from 1967 to 1977. Nevertheless, both sources support the conclusion that in recent years the Northern Plains has been the principal region for new irrigation in the West.

Table 2-6. Changes in Total Acres Irrigated by Farm Production Region (1,000 acres)

Region	1945-54	1954-64	1964-74	1945-74
Northern Plains	827	1,723	2,846	5,396
Southern Plains	3,493	1,872	422	5,787
Mountain	506	1,602	- 91	2,017
Pacific	2,715	1,041	262	4,018
17 Western States	7,541	6,238	3,439	17,218

Source: Census of Agriculture, various years.

Growth by Irrigation Region

Further insights into past trends and the potential for continued growth of irrigated agriculture can be gained by focusing on areas which are more homogeneous than the farm production regions with regard to the factors influencing irrigation. The West would have to be divided into scores of regions to provide study areas which are relatively homogeneous with regard to crops, soils, climate, and water sources. Fortunately, such detail is not necessary for achieving the objectives of this study. As a compromise, the West has been divided into eight irrigation regions and three subregions (identified both in the notes to table 2-7 and in the map included as figure 1-1) which provide a better focus on different water supply situations important for both past and future growth of irrigation.

Since these regions do not conform to state boundaries, county level data available only in the agricultural censuses are required to describe their irrigation. Shortcomings of the recent census data noted earlier suggest the growth rates and percentages in table 2-7 should be used cautiously. Specifically there is reason to expect that the growth rates for the 1964-74 period are understated. For examining major changes in the growth and importance of irrigation in the designated irrigation districts, the census data are instructive. Very distinctive broad trends are apparent in the data, and it is unlikely that these have been distorted significantly by the problems with the census data.

A major consideration in making the regional divisions was to isolate the High Plains, an area covering parts of six states. There is no universally accepted definition of the High Plains. For this paper, High Plains is defined as those parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas which both overlie the Ogallala groundwater formation and fall south of the Platte River.[1] This definition, which excludes parts of Nebraska and the Dakotas commonly included in definitions of the High Plains, is adopted to focus on a region where groundwater is virtually the sole water source, the aquifer is isolated from surrounding formations, and natural recharge is relatively insignificant. Thus, it spotlights an important and extensive agricultural region where irrigation is resulting in large-scale mining of

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[1] Since the census data are based on political and not hydrological boundaries, the area included does not conform exactly to our criteria. The counties included in our definition of the High Plains are listed in the note to table 2-7.

Table 2-7. Growth of Irrigation by Irrigation Region

Irrigation regions[a]	Average annual growth rate of irrigated acres (percent/year)				Contribution to the growth of total irrigated acreage in the West (percent)			
	1945-54	1954-64	1964-74	1945-74	1945-54	1954-64	1964-74	1945-74
(1) High Plains	20.0	5.2	2.9	8.7	39	38	58	42
(a) Southern	25.0	3.1	-0.3	8.2	33	16	-3	19
(b) Central	28.8	12.8	5.6	14.5	3	10	18	8
(c) Northern	6.9	9.4	7.7	8.0	3	13	42	14
(2) Eastern Oklahoma and Texas	8.0	1.9	0	3.1	12	6	0	8
(3) Central Plains	7.4	6.5	6.0	6.6	7	16	51	19
(4) Dakotas	6.0	3.5	2.1	3.8	1	1	1	1
(5) Inter-Mountain	-0.1	1.4	-0.6	0.3	-1	22	-17	4
(6) Southwest	3.1	0	0.1	1.0	6	0	0	2
(7) California	4.0	0.8	0.2	1.6	28	9	4	16
(8) Northwest	3.6	2.0	0.4	1.9	8	8	3	7
Western States	3.7	2.1	1.0	2.2	100	100	100	100

Source: Agricultural Censuses, various years.

[a] See next page

Note to table 2-7.

[a]Irrigation regions

(1) High Plains

(a) Southern: Includes 33 Texas counties (Oldham, Potter, Carson, Gray, Wheeler, Deaf Smith, Randall, Armstrong, Donley, Parmer, Castro, Swisher, Briscoe, Bailey, Lamb, Hale, Floyd, Motley, Cochran, Hockley, Lubbock, Crosby, Yoakum, Terry, Lynn, Garza, Gaines, Dawson, Andrews, Martin, Howard, Midland, and Glasscock).

(b) Central: Includes 10 Texas counties (Dallam, Sherman, Hansford, Ochiltree, Lipscomb, Hartley, Moore, Hutchinson, Roberts, and Hemphill); 6 Oklahoma counties (Cimarron, Texas, Beaver, Harper, Ellis, and Woodward); 6 New Mexico counties (Lea, Roosevelt, Curry, Quay, Union, and Harding.)

(c) Northern: Includes 34 Kansas counties (Morton, Stevens, Seward, Meade, Clark, Stanton, Grant, Haskell, Gray, Ford, Hamilton, Kearny, Finney, Greeley, Wichita, Scott, Lane, Wallace, Logan, Gove, Trego, Sherman, Thomas, Sheridan, Graham, Cheyenne, Rawlins, Decatur, Norton, Phillips, Kiowa, Hodgeman, Ness, and Rooks); 11 Colorado counties (Bace, Prowers, Kiowa, Cheyenne, Kit Carson, Yuma, Washington, Phillips, Logan, Sedgwick, and Lincoln); 9 Nebraska counties (Dundy, Chase, Perkins, Hayes, Hitchcock, Red Willow, Furnas, Frontier, and Harlan).

(2) Eastern Oklahoma and Texas: Texas and Oklahoma excluding the High Plains

(3) Central Plains: Kansas and Nebraska excluding the High Plains

(4) Dakotas: North and South Dakota

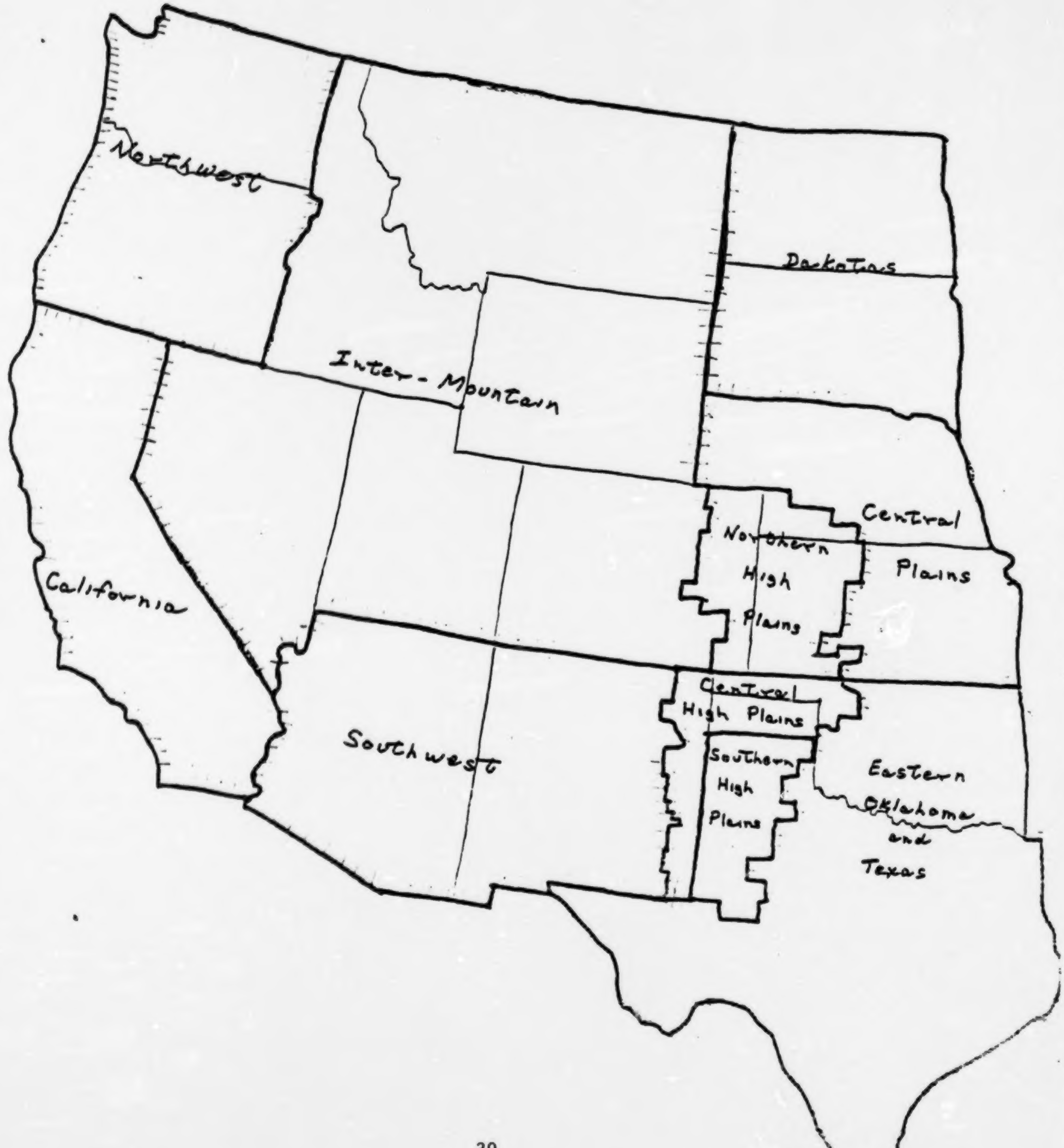
(5) Inter-Mountain: Colorado excluding the High Plains, Idaho, Montana, Nevada, Utah, and Wyoming.

(6) Southwest: Arizona and New Mexico excluding the High Plains

(7) California

(8) Northwest: Oregon and Washington.

Figure 2-1. Map of Western Irrigation Regions


Northwest
Dakotas
Inter-Mountain
Central
Plains
Northern
High
Plains
California
Central
High Plains
Southern
High
Plains
Southwest
Eastern
Oklahoma
and
Texas

the water resources essential to continued irrigated farming. The severity of the regional problem is noted in the Second National Water Assessment which lists groundwater overdrafts estimated at about 14 million acre feet per year in the High Plains among the nation's most critical water problems.[1]

Additional reasons for according the High Plains special attention are suggested by the data in table 2-7 which indicates the average annual growth rates as well as the regional contribution to the overall expansion of western irrigation of the various irrigation regions for the 1945 to 1974 period and three subperiods. The High Plains accounted for more than four of every ten new acres irrigated in the West between 1945 and 1974, and by 1974 this region had 22 percent of the total land irrigated in the West. Although the rate of growth as well as the annual change in the number of acres irrigated has declined sharply in the High Plains, this region's percentage contribution to the growth of western irrigation rose from about 38 prior to 1964 to 58 from 1964 to 1974.

Since there have been marked changes in the growth of irrigation within the High Plains, the area is further divided into three subregions. Early growth was heavily concentrated in the southern High Plains, i.e., Texas, south of the Canadian River. More recently census data suggest irrigated acreage in this subregion has declined slightly. While the average annual rate of growth in the central High Plains, i.e., west Texas north of the Canadian River, eastern New Mexico, and the Oklahoma Panhandle, has declined roughly in half every ten years since 1945, the change in acres irrigated within this subregion as well as its percentage contribution to the total growth of irrigation in the West increased. Since 1964, the most rapid growth of irrigation has been in the northern High Plains, i.e., western Kansas, eastern Colorado, and western Nebraska south of the Platte River, which accounted for 42 percent of the total growth of western irrigation from 1964 to 1974.

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[1] U.S. Water Resources Council, The Nation's Water Resources 1975-2000, Second National Water Assessment, 1978, vol. 1, p. 78.

Overall, there has been a dramatic change in the growth centers of western irrigation. From 1945 to 1954, 79 percent of the growth of irrigated acreage was in a southern belt including eastern Oklahoma and Texas, the southern High Plains, the Southwest, and California. In subsequent decades the contribution of this southern region to the overall growth of irrigation declined to 31 percent and then 1 percent. In contrast, the Central Plains and northern High Plains combined contribution to the expansion of western irrigation rose from 10 percent in the 1945 to 1954 period, to 29 percent in the 1954 to 1964 period, and to 93 percent in the 1964 to 1974 period according to census data.[1]

CROPPING PATTERNS AND TRENDS

Acreage changes, of course, are only one aspect of understanding irrigation's contribution to the overall performance of agriculture. Considered alone the acreage estimates reveal nothing about the impacts on yields, cropping patterns, and the land required to produce a given level of output. Thus, to proceed with the analysis of the role of irrigation requires data on the crop mix and the yields of irrigated and dryland farming.

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[1] The contribution of the Central Plains and northern High Plains to overall growth in the 1964 to 1974 period probably is overstated by these numbers. According to census data, western irrigation outside the High and Central Plains declined between 1964 and 1974 due to a 600,000 acre decline in the Inter-Mountain region and only modest increases in other regions. Although the combination of the CNI and NRI data contradict the conclusion that irrigation has declined outside the Central and High Plains, as was noted earlier, these data do confirm the conclusions drawn from the census data as to where most of the expansion has occurred.

The agricultural censuses are the only sources of comprehensive acreage data for individual crops which also differentiate between irrigated and dryland. Although the acreages of at least the most recent censuses are understated, there is no reason to expect that the census data distort the relative acreage allocated to individual crops. To the contrary, 1969 and 1974 census estimates of the percentage of total irrigated land allocated to row and close-grown crops in each of the West's farm production regions are very close to percentages projected from 1967 CNI and 1977 NRI data.[1] Consequently, the subsequent examination of cropping patterns and trends relies on census data to determine the percentages of irrigated land devoted to individual crops or crop groups.

In 1974 the West's irrigated lands were allocated 42 percent to grains, 22 percent to hay, 10 percent each to pasture and cotton, and 9 percent to vegetables and orchards (see table 2-8). Corn with 18 percent of all irrigated land was the single most important crop in terms of acreage; wheat with 9 percent and sorghum with 7 percent were also important irrigated crops.

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[1] For example, estimates for 1974 of the percentage of irrigated land in the seventeen western states allocated to various crop groups are 45.3 in row and 17.4 in close-grown crops according to the census and 42.5 in row and 17.5 in close-grown crops according to a projection which starts with the 1967 CNI and 1977 NRI data and assumes the acreage of each crop group grew linearly over the decade. Row crops include all corn, all sorghum, cotton, soybeans, other field crops, vegetables, and what the census lists as other crops. Close-grown crops include wheat, other small grains, and field seed crops.

Table 2-8. Irrigated Acreage by Crop Group in the 17 Western States; 1950-1974 (percentages of total acres irrigated in the West)[a]

	1950	1954	1959	1964	1969	1974
Grains: total	22	24	25	27	37	42
Corn[b]	3	3	6	6	12	18
Sorghum[b]	3	6	7	8	11	7
Wheat	4	3	4	5	6	9
Other Small Grains	12	12	8	8	9	8
Cotton	10	11	10	9	9	10
Vegetables & Orchards	n.a.	n.a.	9	8	9	9
Hay	25	25	22	23	23	22
Pasture	16	n.a.	16[c]	16	12	10
All Other	n.a.	n.a.	18	17	11	8

Source: Calculated from census data. The 1950, 1954 and 1959 data are from 1959 Census of Agriculture, Vol. III, Irrigation of Agricultural Lands, summary table 5.

[a] Percentages may not add due to rounding. The 1950 to 1964 percentages are based on data for all farms while the 1969 and 1974 percentages are for class 1-5 farms only.

[b] Corn and sorghum grown for all purposes.

[c] Includes cropland irrigated but not harvested

With the exception of grains which increased and pasture and minor crops (listed as "all other" in the tables) which declined, there was very little change in the relative area allocated to the major crop groups from 1950 to 1974. Grains increased their share of irrigated acreage by 20 percent over this period, and corn, which rose from 3 to 18 percent of the total, accounted for three-fourths of the grain increase. Wheat and sorghum acreage also rose as a percentage of the total while other small grains declined. The shift to grains was particularly rapid from 1964 to 1974 when their acreage rose from 27 to 42 percent of the total.

Two underlying trends have contributed to the rise in the proportion of irrigated grains in the West--there was a shift in the crop mix in favor of grains in most irrigation regions and the regions with the highest irrigation growth rates were those with traditionally high concentrations of grains. For example, the High and Central Plains, which accounted for most of the net growth of irrigated acreage in recent years, have the highest percentages of irrigated land in grains (see table 2-9). In the case of corn which rose from 6 to 18 percent of total irrigated land in the West between 1964 and 1974, 27 percent of this percentage increase was due to the faster overall growth of irrigation in the traditional corn-growing areas and 73 percent was due to a change in the crop mix within the designated irrigation regions and subregions.

IMPACTS OF IRRIGATION ON PRODUCTION AND YIELDS OF CORN, SORGHUM, WHEAT, AND COTTON

Irrigation, with its higher than average yields and growth, clearly has become a more important factor in the production of many crops. To determine just how important requires production and yield data differentiating

Table 2-9. 1974 Irrigated Acreage by Crop in Selected Irrigation Regions

(Percentages of Total Acres Irrigated In Each Region)[a]

Irrigation Region	Grains[b]									
	Total	Corn	Sorghum	Wheat	Other Small Grains	Cotton	Vege-tables & Orchards	Hay	Pasture	All Other
1. High Plains	72	29	24	18	1	16	c	3	2	6
A. Southern	56	12	30	12	1	34	c	1	2	7
B. Central	90	16	35	38	1	1	c	2	3	3
C. Northern	86	60	10	16	c	c	c	7	2	5
2. Eastern Oklahoma and Texas	40	c	9	4	27	27	8	11	8	6
3. Central Plains	83	77	5	1	c	c	c	8	2	7
4. Dakotas	47	34	1	8	4	c	c	39	5	10
5. Inter Mountain	23	6	1	7	9	c	1	46	19	11
6. Southwest	26	2	8	11	5	33	10	23	7	1
7. California	24	5	2	5	13	15	30	16	9	6
8. Northwest	22	3	c	15	4	—	13	33	16	17
17 Western States	42	18	7	9	8	10	9	22	10	8

Source: Calculated from 1974 Census of Agriculture data.

[a] Percentages may not add due to roundings .

[b] Includes corn and sorghum grown for all purposes.

[c] Less than 0.5 percent.

between dryland and irrigated farming. The 1969 agricultural census is the most recent source of such data which covers all states. This source, however, is neither recent nor reliable enough for analyzing the current role of irrigation on national agricultural production and land needs. Lacking any suitable single source, data from the 1974 census, the 1977 NRI, and various state crop and livestock reporting boards are combined to estimate the 1977 dryland and irrigated harvested acreage of individual crops.[1] The yield estimates are based on trends which eliminate or at

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[1] The 1977 acreage estimates start with the 1974 census data on irrigated and dryland crop acreage for each of the seventeen western states. The 1974 census data are not used directly since they understate irrigated acreage. The Soil Conservation Service's 1977 NRI has irrigated and dryland acreage data for the broad categories row and close-grown crops. For each state the ratio of 1977 NRI irrigated (dryland) row crops to 1974 census irrigated (dryland) row crops is multiplied by the 1974 census irrigated (dryland) acreages for corn, sorghum, and cotton. The 1974 census wheat acreages of each state are adjusted by a similarly calculated ratio for close-grown crops. These adjustments are intended to compensate for three factors--the growth from 1974 to 1977, the undernumeration of the census irrigation data, and the fact that the census crop data only include farms with sales of $2,500 or more.

The above adjustment assumes that the acreage of each crop grew at the same rate as the acreage of the entire crop group. This assumption seems reasonable for wheat which comprises the great majority of the close-grown crops. A further adjustment is required, however, to allow for differences in growth from 1974 to 1977 of the individual row crops. Unfortunately, there are only partial data available for determining these differences. For corn the ratio of irrigated (dryland) corn acreage to irrigated (dryland) row crop acreage in 1977 was divided by the comparable ratio for 1974. This ratio was then multiplied by the initial estimate of 1977 irrigated (dryland) corn acreage. Similar adjustments were made for sorghum and cotton. The state crop and livestock reporting boards are the only sources of data required to calculate these ratios but only some of the states have such data. Consequently, the available data were combined to estimate a regional adjustment factor for each of the row crops.

(continued on page 47)

least reduce the impact of short-term fluctuations resulting from the weather or other factors.[1]

In view of the data deficiencies and the problems involved in compensating for them, analysis of the impact of irrigation on land needs and yields is limited to the production of four principal crops--corn, sorghum, wheat, and cotton. In 1974 these crops accounted for about 44 percent of the nation's irrigated cropland and 52 percent of all harvested cropland; the West accounted for about 96 percent of the irrigated acreage of these crops. The acreage and yield estimates for 1977 along with the implied production levels are presented in table 2-10.

Irrigation provides much higher yields than the western dryland alternative for all four crops but especially corn and cotton. In the more arid areas of the West, of course, there is no viable dryland alternative for these crops. While the yield advantage of irrigation over eastern production is smaller, with the exception of wheat it is still sizable. For example, the 1977 western irrigated trend yields exceeded the comparable dryland West and all East corn, sorghum, wheat, and cotton yields by the following percentages:

	Corn	Sorghum	Wheat	Cotton
Dryland West	139	70	45	135
East	30	26	3	37

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continuation of footnote

Since the NRI crop acreage estimates include temporarily idled land and all acreage planted, further adjustment of the 1977 crop acreages was made to convert the estimates to a harvested acreage basis. This was done by assuming that the previously calculated figures correctly reflect the ratio of irrigated to dryland acres and that the U.S. Department of Agriculture's Statistical Reporting Service data are the most accurate estimates of total harvested crop acreage.

[1] Estimated yields for both irrigated and dryland production are based on fitting a linear regression to actual yields in 1950, 1954, 1959, 1969, 1974, and 1977. Census data are used for the 1950 through 1969 observations. The more recent yield data are based on crop and livestock reporting broad data for all those western states providing data which differentiate between irrigated and dryland acreage and yields.

Table 2-10. Irrigated and Dryland Acreage, Yields, and Production of Corn, Sorghum, Wheat, and Cotton for 1977

		Acreage harvested (1000 acres)	Trend Yields (bushels/acre)	Production[b] (millions of bu.)
Corn[a]:	Irrigated West	8,838	115.2	1,018
	Dryland West	4,572	48.3	221
	East	56,596	88.6	5,014
	U.S. Total	70,006	89.3	6,253
Sorghum[a]:	Irrigated West	1,847	77.4	143
	Dryland West	10,774	45.5	490
	East	1,444	61.4	89
	U.S. Total	14,065	51.3	722
Wheat:	Irrigated West	3,899	39.4	154
	Dryland West	49,387	27.1	1,338
	East	12,930	38.4	497
	U.S. Total	66,216	30.0	1,989
			(bales/acre)	(1,000 bales)
Cotton:	Irrigated West	3,868	1.41	5,454
	Dryland West	5,212	0.60	3,127
	East	4,199	1.03	4,325
	U.S. Total	13,279	0.97	12,906

[a] For grain only.

[b] Production is calculated as the acreage harvested times the trend yield; this is not actual production.

Sources: The total acreage estimates for the West and United States are from U.S. Department of Agriculture, Agricultural Statistics 1978, Government Printing Office, Washington, D.C. Derivation of the irrigated and dryland acreages and the trend yields are explained in the notes on pages 2-23 and 2-24.

There were sizable increases in the production and yields of all four crops from 1950 to 1977. Indeed, although the combined acreage harvested was virtually unchanged for these four crops, average yields and production rose about 122 percent.[1] This performance was notably superior to the 68 percent increase achieved in the yield index of all harvested crops.[2] Undoubtedly the 383 percent increase in the irrigated acreage of these four crops (compared to the approximate doubling of total irrigated acreage) was a factor in their higher yield increases. The following analysis, which attempts to quantify the irrigation factor, starts from table 2-11 indicating the percentage changes in acreage, trend yields, and production of these four crops for the United States, the irrigated West, the dryland West, and the East.

While many factors affect crop production, the focus here is limited to the role of irrigated and dryland acreage and yields. Western irrigation generally implies more intensive use of complementary inputs such as fertilizers and pesticides, and the higher yields on irrigated lands are the result of the entire input package. No attempt, however, is made to explain the impact of these other inputs. Indeed, the data are not available to differentiate between the use of these inputs on irrigated and dryland farming. At least in the arid and semiarid West, controlled water is essential for the introduction of high-yielding agriculture and, thus, is a controlling element in the region's agricultural expansion.

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[1] The average yield increase is the weighted average of the change in trend yields where the weights are the mean of the 1950 and 1977 acreage harvested. The 1950 crop acreage data for the United States, the East, and the total West are from U.S. Department of Agriculture, Agricultural Statistics 1952, U.S. Government Printing Office, Washington, 1952. The relative breakdown between western irrigated and dryland acreage is based on the data in the 1950 Census of Agriculture.

[2] Data on total cropland harvested and an index of crop production per acre are in U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, Changes in Farm Production and Efficiency, 1977, Statistical Bulletin No. 612, prepared by Donald D. Durost and Evelyn T. Black, Washington, D.C., November 1978.

Nationally, corn, sorghum, and wheat output at least doubled while cotton output rose by only 18 percent. Irrigated production generally grew much faster than the total; for example, the percentage increases in irrigated production were 4748 for corn, 251 for sorghum, 470 for wheat, and 175 for cotton. The rapid growth of irrigated output is partly due to relatively low base year levels. Thus, despite the rapid growth, irrigation accounted for only 28 percent of the national corn production increase, 20 percent for sorghum, and 12 percent for wheat. Eastern cotton production declined sharply over this period, and irrigation accounted for 175 percent of the national increase in cotton production. Table 2-12 indicates the relative importance of changing acreage, yields, and production within the irrigated West, the dryland West, and the East on the national change in the production of these four crops.[1]

Yield rather than acreage increases were the major factors underlying the national production changes. Indeed, total acreage declined for two

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[1] The changes in irrigated West, dryland West, and eastern production initially were divided into three components each: that due to the change in acreage with yield held constant, that due to the change in yield with acreage held constant, and that due to the impact of the change in acreage on the change in yield, which is referred to as the interaction effect. The sum of these three components is equivalent to the total change in production for each category. This can be demonstrated by starting with the following definition:

$P_t^i \equiv A_t^i \cdot Y_t^i$ where P_t^i is irrigated production in year t; A_t^i is irrigated acreage in year t; and Y_t^i is the average yield on irrigated land in year t. If Δ indicates the change between years 0 and t, then

Table 2-11. Changes in Irrigated and Dryland Acreage, Yields, and Production of Corn, Sorghum, Wheat, and Cotton, 1950 to 1977 (in percentages of 1950 levels)

	Change in estimated acres harvested	Change in trend yields	Change in production
Corn: Irrigated West	1842	144	4748
Dryland West	-73	78	-51
East	2	126	130
U.S. Total	- 4	145	136
Sorghum: Irrigated West	107	70	251
Dryland West	16	151	191
East	1028	190	3185
U.S. Total	36	150	241
Wheat: Irrigated West	328	31	470
Dryland West	2	96	99
East	7	77	90
U.S. Total	7	92	107
Cotton: Irrigated West	148	11	175
Dryland West	-25	50	12
East	-55	56	-30
U.S. Total	-26	59	18

Sources: The text and the notes on pages 2-23 to 2-26 indicate the sources of the data used for this table.

of the four crops and, therefore, acreage changes had a negative impact on production in these cases. On the other hand, increased irrigated acreage accounted for 60 percent or more of the increases in the irrigated output of these crops.

Average yields rose for all four crops in all regions considered. Nationally, corn and sorghum yields more than doubled, wheat yields rose

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(continuation of footnote 2

$$(1)\ \Delta P^{i} \equiv P_{t}^{i} - P_{o}^{i} = \Delta A^{i} . Y_{o}^{i} + \Delta Y^{i} . A_{o}^{i} + \Delta A^{i} . \Delta Y^{i}.$$

Thus, the change in irrigated production equals the sum of the three components on the right-hand side of the equation: the change in dryland West and eastern production also can be divided into three comparable components.

Since irrigated acreage was relatively small in the initial year (1950) and grew much faster than dryland acreage in the following decades, use of the equation in this form gives much greater weight to nonirrigated as opposed to irrigated yield changes. Furthermore, much of the production change is not attributed specifically to either yield or acreage changes because of the sizable interaction term. Consequently, the interaction term has been eliminated by rewriting equation (1) in the following but equivalent form:

$$(2)\ \Delta P^{i} = \Delta A^{i}\, \overline{Y}^{i} + \Delta Y^{i} . \overline{A}^{i}$$

where $\overline{Y} \equiv (Y_{o} + Y_{t})/2$ and $\overline{A} \equiv (A_{o} + A_{t})/2$. This equation weights the change in acreage (yield) terms by the average yields (acreages) rather than by the initial year levels. By eliminating the interaction term, the entire change in irrigated (dryland) production is divided among two terms, the change in yield and the change in acreage. The change in the total production of a given crop is equal to the sum of the changes for the irrigated West, dryland West, and East. Thus, total production change for each crop within a given region is divided into six components in table 2-11.

There are no "correct" weights for separating out the contribution of dryland and irrigated acreage and yield changes to the change in crop production. In comparison to the results presented in table 2-11, initial year weights decrease and final year weights increase the role attributed to irrigation yields.

Table 2-12. Sources of Corn, Sorghum, Wheat, and Cotton Production Growth, 1950 to 1977 (in percentages of the change in the U.S. production of each crop)

	Change in acres harvested	Change in Yields	Change in Production
Corn for grain:			
Irrigated West	19	9	28
Dryland West	-13	6	-6
East	2	77	79
U.S. Total	-5	104	100
Sorghum for grain:			
Irrigated West	12	9	20
Dryland West	9	54	63
East	11	6	17
U.S. Total	26	74	100
Wheat:			
Irrigated West	10	2	12
Dryland West	2	63	65
East	2	20	23
U.S. Total	10	89	100
Cotton:			
Irrigated West	156	19	175
Dryland West	-44	61	17
East	-218	126	-92
U.S. Total	-182	281	100

Source: The underlying data are explained in the notes on pages 2-23 to 2-26. The note on page 2-28 explains the derivation of the acreage and yield contributions.

92 percent, and cotton yields rose 59 percent. Both dryland and irrigated yield trends were up, and with the exception of irrigated cotton which rose 11 percent and irrigated wheat which rose 31 percent, yields rose by 50 percent or more (see table 2-11).

The change in aggregate crop yields can be divided into four contributing factors. Three of these factors, the yield changes in the irrigated West, the dryland West, and the East, are included in table 2-12, which shows their contribution to the change in production. The fourth factor results from changes in the relative regional and irrigated/dryland distribution of the total acreage. That is, since irrigated yields are generally higher, average crop yields rise as the percentage of the land irrigated rises. This occurs even with no change in average irrigated and dryland yields.

Table 2-13 presents the percentage changes in aggregate crop yields between 1950 and 1977 and indicates the percentage contributions of the four factors to these yield increases. It is evident from this table that the increases in yields in the East and dryland West were the dominant factors underlying the rise in national average yields. Since virtually all eastern production of these crops is dryland, we can conclude that total dryland yield increases accounted for about 80 percent or more of the total increase in corn, sorghum, and wheat yield increases and about 67 percent of the cotton yield increases. While the growth rate of yields was higher for dryland wheat, sorghum,and cotton than for irrigated production of these crops, the principal reason for the dominance of dryland yields is that nationally the great majority of the acres harvested are dryland. Thus, an increase in average dryland yields has a much greater impact on national production and yields than does a comparable increase in irrigated yields.

Table 2-13. Changes in Total Crop Yields and the Sources of Changes, 1950 to 1977 (in percentages)

		Sources of Crop Yield Changes (percentages of total change in yields)			
	% Change in Aggregate Yield	Growth of Yields in Irrigated West	Growth of Yields in Dryland West	Growth of Yields in East	Change in acreage mix
Corn	145	8	6	74	12
Sorghum	150	12	74	8	6
Wheat	92	3	71	23	4
Cotton	59	7	22	45	27

The importance of the percentages of land irrigated and nonirrigated is most strikingly illustrated in the case of corn. In spite of a 144 percent rise in irrigated corn yields, a 1842 percent rise in irrigated acreage, and a 4 percent decline in total acreage, the increase in irrigated corn yields accounted for only 8 percent of the national increase in corn yields.

For corn, wheat, and cotton, the change in the acreage mix had a greater impact on aggregate yields than did the change in yields on irrigated lands (see table 2-13). The most notable case is cotton for which the change in the acreage mix accounted for 27 percent of the national yield increase. With the exception of sorghum, the largest acreage increases were for the irrigated West; for all four crops, irrigated acreage rose as a percentage of the total. Consequently, much of the contribution to yields stemming from the changing acreage mix is attributable to the increased role of irrigation. Table 2-14 separates the contribution of the change in the acreage mix to the growth of total yields into that attributable to (a) the shift from dryland (i.e., dryland West plus East) to irrigated acreage and (b) the shift from dryland West to eastern acreage.[1] Adding the impact of the increasing role of western irrigation (from table 2-14) to the impact of the change in western irrigated yields (from table 2-13), suggests the total percentage impact of irrigation on the growth of national yields was 13 for corn, 16 for sorghum, 7 for wheat, and 44 for cotton.

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[1] The impact of the increasing role of irrigation on national crop yields is determined by aggregating the dryland West and East and redoing the component analysis of yield changes described in the note on page 2-28. With only two types of farming considered, irrigated West and all other, the yield impact of change in the acreage mix is equivalent to the impact of the change in the role of western irrigation. The difference between the yield changes attributable to the change in the acreage mix (from table 2-13) and that attributable to the shift from dryland to irrigated acreage (from table 2-14) is due to the relative shift from dryland West to eastern production (presented in table 2-14). With the exception of cotton, all the relative shifts in acreage had positive impacts on national yields. While the changes in the role of irrigation explained 37 percent of the growth of national cotton yields, the change in relative dryland West and all East acreage reduced national yields by 10 percent over this period.

Table 2-14. Impact of the Change in Acreage Mix on National Crop Yields, 1950 to 1977
(as a percentage of the change in national yields)

	Shift from dryland to western irrigation	Shift between dryland West and East
Corn	5	7
Sorghum	4	2
Wheat	4	0
Cotton	37	-10

IMPACTS OF IRRIGATION ON LAND USE

Irrigation has two principal impacts on the supply and demand of farmland. Irrigation reduces the amount of land required to produce a given output (i.e., it is a land-conserving technology) and expands the land suitable for commercial farming (i.e., it might be considered an agricultural land-creating technology).

As noted above yields tend to be higher on irrigated than on dryland farms, especially in the West where rainfall is low and unreliable. Improved yields stem both from the greater control irrigation provides over water and from the complementary investments in yield-increasing inputs such as agricultural chemicals and improved seed which are profitable only where there is an assured supply of water. The capital invested in the entire package of yield-increasing inputs associated with irrigation can be viewed as a substitute for land in an agricultural production function. One way of illustrating the importance of the land-conserving impact of irrigation is to speculate as to the amount of additional land that would be required to produce the 1977 level of output without irrigation. The answer, of course, depends on what happens to dryland yields both on the intensive (i.e., the lands already in production) and extensive (i.e., the additional lands devoted to dryland production) margins. There is no way to know what would happen to yields under such circumstances but illustrating the implications of several assumptions provides a ballpark estimate of the land-conserving impacts of irrigation.

Assuming no change on the intensive margin and yields equivalent to the 1977 combined average of the East and dryland West, an additional 7.1 million harvested acres would be required to compensate for the irrigated production of corn, sorghum, wheat, and cotton. This estimate contains two somewhat offsetting biases. On the one hand, the lands involved in a 25.6 million acre expansion of dryland production are likely on average to be of lower quality than those already in production. Thus, unless farmers compensated with higher levels of investment or management, average yields on the new lands would fall below the overall dryland average. On the other hand, this estimate makes no allowance for increasing yields on those lands already under dryland farming. For example, if conditions called for a major expansion of agricultural production, investment would be directed to increasing yields on currently cropped lands as well as to developing new farmlands. On balance, 7 million acres may be a reasonable estimate of the land-conserving implications of the 18.5 million acres irrigated to these four crops.

The land-conserving impacts of irrigation almost certainly are greater than 7 million acres since these four crops accounted for only about 44 percent of the West's irrigated acreage in 1974. The lack of comparable data differentiating between irrigated and dryland yields of most other crops has deterred any effort to extend this analysis to additional crops. But even if there were no problems with the data, comparing land requirements with dryland and irrigated production becomes more questionable when applied to some of the other crops. In particular, the comparison ignores the difficulties of growing on dryland farms some of the high-value speciality crops which are grown almost exclusively under irrigation.

Irrigation also expands the agricultural land base by opening up arid and semiarid areas to high-yielding agriculture. In particular, unirrigated arid areas have made little to no contribution to agriculture. There is no way to know just how much of the irrigated land would be removed from agriculture in the absence of irrigation. Certainly, most of the lands in the predominantly arid states of Arizona, Nevada, New Mexico, and Utah, much of California, and parts of most of the other western states would not be cropped in the absence of irrigation. A very rough estimate of the land-creating implications suggests irrigation has expanded the acreage suitable for agriculture by 10 to 13 million acres. The higher figure is roughly equivalent to the 1977 irrigated cropland in Arizona, California, Nevada, New Mexico, and Utah.

Recent interest in the commercial potential of several plants native to arid and simiarid areas raises the possibility that these lands may contribute to the agricultural land base in the absence of irrigation. Three of the most promising such plants are jojoba, guayule, and *Euphorbia lathyris*. Jojoba, a drought resistant plant that occurs naturally in areas with 3 to 15 inches annual rainfall, produces a liquid wax which makes an excellent industrial lubricant. Guayule, a drought tolerant plant that can be grown commercially with 11 inches of water per year, produces a latex substance that can be partially substituted for synthetic rubber made from petroleum products. Indeed, guayule was grown in the United States as a source of rubber prior to and during World War II. Euphorbia lathyris, which also grows naturally in an arid environment, is a potential source of fuel oil. A noted University of California chemist, Melvin Calvin, is seeking to develop varieties capable of producing oil on a commercial basis.

Despite their promise, the chances that these or other crops will be grown commercially in arid areas without irrigation is highly problematical. Native arid-land plants occur naturally only in densities that are too low for commercialization. While research is likely to improve yields and other commerical properties, growing these plants profitably in arid areas may require irrigation. On the other hand, the water needs of these plants will be much lower than the requirements of the crops commonly irrigated in arid areas, a feature which may make them increasingly attractice as water becomes scarcer.[1]

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[1] A more extensive discussion of these three as well as several other arid-land plants is available in a summary of the February 7, 1980 conference "New Crops for California Agriculture" which has been reproduced by Continuing Education in Agricultural Sciences and Management, University Extension, University of California, Davis.

SECTION 3

WATER AS A CONSTRAINT ON WESTERN IRRIGATION

The seventeen western states accounted for 84 percent of the 1975 U.S. fresh water consumption (defined as the portion of water withdrawn for offstream use which is not returned to a surface or groundwater source). On a per capita basis western water consumption was 12.4 times that in the East.[1] Since the West receives only about one-fourth of the rainfall, it is evident that high western water consumption levels do not reflect adoption of a development pattern focused on exploiting an abundant regional resource. To the contrary, the level of western water consumption in large part results from efforts to overcome the limitations of natural supplies. In particular, with the exception of some mountainous areas and a narrow coastal strip in the Northwest, rainfall west of the 100th meridian is insufficient to support high productivity dryland agriculture. The combination of the sizable water requirements associated with irrigation and, as is explained below, a deliberate government policy of encouraging western irrigation, led to the situation in 1975 where 90 percent of western freshwater consumption was for irrigation. And in view of the magnitude of the water used by western irrigators, it is not surprising that the most critical water supply problems identified by the Second National Water Assessment are located in the West.[2]

WATER DEVELOPMENT FOR IRRIGATION

The expansion of irrigation was facilitated by easy access to low cost water. Initial development was based primarily on directing surface waters to neighboring fields. Level valley lands that could be irrigated with gravity flows were the first to be developed. Subsequent expansion required canals, dams, and pumps to transport water longer distances and to increase the assured supply. Higher costs and an increasing dependence on nonrenewable groundwater supplies have resulted from this growth.

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[1] C. Richard Murray and E. Bodette Reeves, Estimated Use of Water in the United States in 1975, U.S. Geological Survey Circular 765, pp. 8-9.

[2] U.S. Water Resources Council, The Nation's Water Resources 1975-2000, The Second National Assessment, vol. 1; Summary, December 1978, pp. 56-59.

The Federal Role

The Bureau of Reclamation, recently renamed the Water and Power Resources Service (WPRS), was established in 1902 to reclaim arid western land through irrigation. WPRS projects helped ensure that the financial and engineering requirements of these water projects did not prevent the spread of irrigation. Lands receiving either full or supplementary irrigation water through federal projects rose to 400,000 acres by 1910, 3,000,000 acres by 1930, and over 11,000,000 acres by 1980. In recent years these projects provided at least some irrigation water to about one-fifth of the irrigated lands and full irrigation to about one-tenth of the acreage. Through time the WPRS role has expanded to providing water for municipal and industrial use, hydroelectric power, water channels for navigation, flood control, and recreational facilities for the public. From 1902 through June 1975, the WPRS had spent $6.0 billion on water related projects in the West; major accomplishments include construction of 326 storage reservoirs, 355 diversion dams, 14,320 miles of canals, and 34,290 miles of laterals.[1]

Despite the stipulation in the 1902 legislation that WPRS should establish charges sufficient to recover all the costs of constructing the projects, the water from these federal projects has been provided to farmers at highly subsidized rates.[1] Initial funds for construction costs were to be supplied by the sale of federal land in the West. Irrigation project costs were to be repaid by the users over a ten-year period with no interest charge; these funds then were to be used for subsequent projects. The intent of the initial legislation, however, bears little relation to what has transpired.

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[1] U.S. Department of Interior, Federal Reclamation Projects, Water and Land Resources Accomplishments, 1975 (Summary Report).

The costs and problems of establishing irrigation on previously unfarmed arid lands were much greater than anticipated, and many farmers were unable to meet repayment requirements. Legislative relief came with the 1914 Reclamation Extension Act, which increased the repayment period to twenty years and provided a five-year grace period. New irrigators paid 5 percent of the costs up front and the balance in fifteen annual installments beginning in the sixth year. But even these more lenient repayment schedules were not met by many farmers, and the 1914 legislation proved to be just the first of a series of legislative and administrative adjustments to the original act that have combined to provide enormous subsidies for federal water projects. Farmers were provided with more beneficial payment terms in 1926 when about $17.3 million or 13 percent of the costs on twenty-one projects were written off and the repayment period was extended to forty years on all projects. The policy of not charging interest remained intact.

Further relief to those fortunate enough to have access to federal water came with the Reclamation Project Act of 1939. This act specified that irrigators were responsible only for that portion of the debt they were able to repay. Farm budgets are used by WPRS to determine the rates farmers could afford. Implementation of the ability-to-pay criterion by WPRS has been confusing but generally very beneficial to the farmers.[1] But almost regardless of the initial level of the water charge, large subsidies were ensured by extending the repayment period to as long as fifty years with a 10-year grace period and keeping the rates fixed throughout the period with no adjustment for inflation.

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[1] Much of the following discussion of the evolution of federal water project policy is based on U.S. General Accounting Office, Federal Charges For Irrigation Projects Reviewed Do Not Cover Costs, PAD-81-07, Washington, March 3, 1981, chapters 1 and 2.

The objective of the earlier WPRS projects was almost exclusively irrigation. More recently projects have been designed to serve multiple purposes, and since the early 1950s, irrigation has been assigned only part of the project costs. The amendment to the Reclamation Act allowing for separable costs intended that recreation, flood control, and fish and wildlife costs be largely non-reimbursable items; these costs were to be covered primarily by tax revenues. Irrigation costs were expected to be paid in full but without interest by the users while power and municipal and industrial users were to repay the costs including some interest charge. In spite of the intent, a 1975 study by the Water Resources Council indicated that non-federal groups had paid only 18 percent of the WPRS irrigation project costs, the same percentage as for the recreation project costs.[2]

Estimates as to the level of subsidy provided irrigators on federal water projects vary depending in part on the projects considered and the interest rate used to discount future payments by irrigators. In all cases, however, dispassionate analysis indicates the subsidies have been generous.

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[1] The General Accounting Office study of six federal irrigation projects found the WPRS' ability-to-pay "analysis to be inaccurate at times and misleading because it does not concentrate on the areas which will actually be irrigated nor on the crops which will be irrigated." U.S. General Accouting Office, Federal Charges for Irrigation Projects, p. ii.

[2] U.S. General Accounting Office, Federal Charges for Irrigation Projects, p. 2.

Analysis of eighteen irrigation districts by the Office of Policy Analysis, U.S. Department of Interior shows a wide range among projects in federal subsidies. The difference between the full costs, defined to include all construction costs allocated to irrigation plus operation and maintenance costs with interest based on long-term government borrowing rates charged on all cost items, and the present value of past and expected future farmer payments is defined as the subsidy. The per acre subsidies range from just $58 for Moon Lake, which receives just supplemental water, to $1,787 for the Wellton-Mohawk district; the subsidy ranges from 57 percent of the costs for Moon Lake to 97 percent for the East Columbia basin (see table 3-1).[1]

Alternative subsidy estimates by LeVeen suggest that at current collection rates and costs, the $3.62 billion the WPRS has spent for irrigation construction will be paid roughly 56.7 percent from electricity sales, 40 percent from general tax revenues, and only 3.3 percent by farmers.[2] In other words, irrigators are barely paying the operating and maintenance (O & M) costs of the projects, and in some cases current charges fail to cover even the O & M costs. For example, the cost of delivering water to the Westlands Water District by WPRS in 1981 was projected to be $10.50 per acre-foot. Nevertheless, the present water rate of $7.50, which was determined in 1954 and implemented in 1968, will remain in effect through

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[1] U.S. Department of Interior, Water and Power Resources Service, Acreage Limitation, Interim Report, March 1980, pp. 37-42.

[2] E. Phillip LeVeen, "Reclamation Policy at a Crossroads," in Public Affairs Report, Bulletin of the Institute of Governmental Studies, University of California, Berkeley, October 1978, vol. 19, no. 5, pp. 2-3.

Table 3-1. Federal Subsidies for Eighteen Irrigation Districts

Region and Irrigation District	Irrigable Acres in District in 1977 (1000 acres)	Subsidy as of 1978 ($ per acre)	Subsidy as a percent of full cost
Pacific Northwest Region			
1. Oroville-Tonasket	9.5	417	82
2. Black Canyon #2	53.2	762	89
3. East Columbia Basin	134.5	1,619	97
Mid-Pacific Region			
4. Cachuma Project	38.7[a]	1,378	81
5. Truckee-Carson	73.0	931	83
6. Glen	152.3[b]	101	91
7. San Luis Unit	571.9	1,422	85
8. Coachella Valley	78.5	1,000	70
9. Wellton-Mohawk	65.8	1,787	89
10. Imperial Valley	519.5	149	74
Upper Colorado Basin			
11. Moon Lake	75.3[b]	58	57
12. Grand Valley	23.3	1,623	85
Southwest Region			
13. Elephant Butte	102.1	363	64
14. Lugert-Altus	47.1	675	90
Upper Missouri Region			
15. Malta	42.4	812	92
16. Lower Yellowstone #1	34.5	507	73
Lower Missouri Region			
17. Farwell	50.1	1,446	93
18. Goshen	52.5	416	74

Source: U.S. Department of Interior, Acreage Limitation, Interim Report, March 1980, pp. 38-41.

[a] 38,151 acres or about 99 percent of the acreage receives only supplemental federal irrigation.

[b] This acreage receives only supplemental federal irrigation.

2008.[1] With allowance for the effects of inflation, conservative assumptions suggest that the present value (in 1976 dollars) of the subsidy averages at least $500 per acre over all WPRS projects. A more definitive estimate for the Westlands Water District suggests the subsidy is three to four times that level.[2] Thus for a 160-acre farm, the total subsidy would be $80,000 at $500 per acre; in the Westlands the subsidy for such a farm might reach about $320,000. Since much of the irrigable land is owned and operated in much larger units, some farmers receive even larger subsidies. In the Westlands Water District, for example, nineteen owners have farms in excess of 1,920 acres. Thus, about one-half of 1 percent of the owners have 35 percent of the land in this district. Based on the size of the farm operation, large farms are even more dominant as 79 percent of the irrigable acreage in the Westlands is in farms larger than 1,920 acres.[3]

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[1] U.S. Department of the Interior, Special Task Force Report on San Luis Unit, U.S. Government Printing Office, Stock No. 024-003-00123-6, Washington, D.C., 1978.

[2] LeVeen, "Reclamation Policy at a Crossroads," p. 3.

[3] U.S. Department of Interior, Water and Power Resources Service, Acreage Limitation-Draft Environmental Impact Statement, January 8, 1981, pp. 3-71 and 3-73. Distribution of federal irrigation subsidies is discussed further in section 4.

A 1981 General Accounting Office (GAO) report to the Congress suggests high subsidy levels will continue with new WPRS projects.[1] The GAO report summarizes their assessment of six projects which were under construction but not completed at the time of the review. The total cost of these projects exceeds $2.1 billion, nearly half of which is attributed to irrigation facilities. Only a tiny fraction of these costs will be paid by irrigators. Using a 7.5 percent discount rate, the fees set by WPRS imply irrigation subsidies ranging from 92.2 to 97.8 percent of the construction costs. The estimated costs of water delivered from these federal projects range from $54 an acre-foot for the Fryingpan-Arkansas project, which distributes supplementary water through existing facilities, to $130 an acre-foot for the Pollock-Herreid project. Yet the WPRS charges to recover the construction costs of this water range from 27 cents (only 7 cents according to GAO calculations) to $9.82 cents per acre-foot.

Irrigation Water Withdrawals, 1950 to 1975

Total surface water withdrawals (defined as the water taken from surface water sources for offstream use) for western irrigation have not increased significantly from the level of 88 million acre-feet reached in 1955 (see table 3-2). Indeed, the 1955 level was not even reached again until 1975. This leveling off of stream flow diversions for irrigation reflected a number of factors including the rising costs associated with developing new supplies, the competition from nonfarm users for undeveloped supplies as well as water previously used for irrigation, and, as is demonstrated below,

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[1] U.S. General Accounting Office, Federal Charges for Irrigation Projects Reviewed Do Not Cover Costs, PAD-81-97, March 3, 1981.

Table 3-2. Ground and Surface Water Withdrawn for Irrigation, 1950-1975

	1950	1955	1960[a]	1965	1970	1975
Northern Plains						
Groundwater (1000 acre-feet)	786	1,636	2,839	4,068	6,165	11,209
Surface (1000 acre-feet)	2,220	2,292	3,702	2,910	2,950	3,120
Total (1000 acre-feet)	3,006	3,929	6,540	6,978	9,115	14,329
Ground as % of total	26	42	43	58	68	78
Southern Plains						
Groundwater (1000 acre-feet)	1,850	7,470	9,252	13,300	9,610	11,100
Surface (1000 acre-feet)	3,130	4,173	3,570	2,910	2,910	2,780
Total (1000 acre-feet)	4,980	11,643	12,822	16,210	12,520	13,880
Ground as % of total	37	64	72	82	77	80
Mountain						
Ground (1000 acre-feet)	5,285	9,906	12,226	11,400	11,311	14,450
Surface (1000 acre-feet)	42,300	53,860	45,411	47,200	52,200	50,900
Total (1000 acre-feet)	47,585	63,766	57,637	58,600	63,511	65,350
Ground as % of total	11	16	21	20	18	22
Pacific						
Ground (1000 acre-feet)	10,270	12,002	11,575	12,830	19,100	19,260
Surface (1000 acre-feet)	18,900	27,700	25,365	26,500	29,600	31,600
Total (1000 acre-feet)	29,170	39,702	36,940	39,330	48,700	50,860
Ground as % of total	35	30	31	33	39	38
17 Western States						
Ground (1000 acre-feet)	18,191	31,014	35,892	41,598	46,186	56,019
Surface (1000 acre-feet)	66,550	88,025	78,047	79,520	87,660	88,400
Total (1000 acre-feet)	84,741	119,039	113,939	121,118	133,846	144,419
Ground as % of total	21	26	32	34	35	39

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[a] 1960 conveyance losses are divided among ground and surface water according to the same percentages indicated by the 1955 data.

Sources: U.S. Geological Survey, Circulars #115, 398, 456, 556, 676, and 765.

relatively little surface water remained to be developed within the areas with the most favorable growing conditions.[1]

Since the mid-1950s, the overall expansion of western irrigation has been based on groundwater, and the increasing importance of groundwater dates back several more decades. From negligible levels in the early 1930s, groundwater withdrawals for western irrigation reached about 10.7 million acre-feet by 1945, 31.0 million by 1955, 41.6 million by 1965, and 56.0 million by 1975. Groundwater as a percent of total irrigation withdrawals increased steadily over this period to 39 percent by 1975 (see table 3-2).[2]

Technological breakthroughs in high-speed engines and turbine centrifugal pumps helped establish deep-well pumping as a viable alternative in the mid-1930s. The combination of these technical advances and widespread drought encouraged the rapid expansion of groundwater irrigation in the late 1930s, especially in the southern High Plains. Additional technological advances as well as access to inexpensive energy for irrigation pumping further stimulated the growth of groundwater irrigation. In particular, the availability of very low cost natural gas and development of the center pivot sprinkler system encouraged the rapid growth of irrigation in the High Plains. Although they were developed in the 1950s, the big expansion of center pivots started in the late 1960s and continued into the 1970s.

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[1] Changes in surface water withdrawals may not be directly related to changes in the acreage irrigated with surface water. For example, improvements in on-farm water efficiency could increase the ratio of irrigated acreage to water withdrawn. However, since there has been little incentive for surface water users to improve irrigation efficiencies, it is not likely that there have been significant changes in this ratio. Furthermore, even if the ratio has increased, it does not necessarily follow that more land is irrigated with surface water since improvements in on-farm efficiency reduce the runoff available for use downstream.

[2] The earliest available data on groundwater withdrawals are in W. F. Guyton, "Estimated Use of Ground Water in the United States--1945" (an unpublished paper prepared at the U.S. Geological Survey). Comparable surface water data are not available for 1945.

From 1945 to 1965 the largest increases in groundwater use were in the Southern Plains; more recently they have been in the Northern Plains. Annual groundwater withdrawals for irrigation in the Southern Plains rose from less than 1 million acre feet in 1945, to nearly 2 million acre-feet in 1950, and 13 million acre feet in 1965. This latter level resulted in substantial groundwater mining (withdrawals in excess of natural recharge), most notably within the southern High Plains of Texas, which is examined in more detail below. Although groundwater withdrawals in the Southern Plains have declined sharply from the 1965 level, in 1975 they still accounted for 80 percent of this region's total irrigation withdrawals.

The most recent growth of western irrigation has been concentrated in the Northern Plains. While groundwater accounted for only 26 percent of 1950 Northern Plains irrigation withdrawals, over the next quarter century 92 percent of the region's increase in irrigation withdrawals were from the ground. Groundwater rose to 78 percent of their total irrigation withdrawals by 1975 (see table 3-2).

WATER SUPPLY ADEQUACY

There are no simple measures indicating the nature and seriousness of a region's water problems. While market price is the normal measure of scarcity, water is seldom allocated within competitive markets. But even if water were allocated competitively, the market price would not measure the social costs of water use because of the common property characteristics of most water supplies and the problems of evaluating the benefits and costs of most water uses.

Water users commonly do not bear the full cost of their use. This is readily apparent when a stream is used for waste disposal, the costs of which are borne by those downstream rather than by the polluter. Private costs also are less than social costs when a farmer's use of groundwater stocks adversely affects the availability of water to neighboring and future users. Private and not social costs affect farmer's irrigation decisions. Thus, when left to private decisions, in such cases water use tends to exceed socially desirable levels and significant costs may be borne by potential downstream neighboring, or future users.

Further complications in assessing a region's or individual's water situation stem from the variety of factors which affect the value of a given quantity of water and the divergent impacts users can have on the supply. Quality, location, timing, and certainty of supply are all important dimensions of water value. But the importance of the various dimensions as well as the impacts of both withdrawals and return flows on these factors vary widely among users. Water withdrawn for use is seldom fully consumed in that use. For example, in 1975 consumption as a percentage of withdrawals averaged 1 percent for thermoelectric power, 11 percent for other industrial uses, 23 percent for public supplies, and 56 percent for irrigation.[1] Consequently, both the portion of the water available for reuse and the characteristics of the return flows are important for determining the social costs of a particular water withdrawal.

Although there is no simple way to assess all the factors affecting a region's water supply situation, water supply and use data from the Second National Water Assessment indicate the pressures on water resources within

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[1] U.S. Geological Survey, Estimated Use of Water in the United States in 1975, Geological Survey Circular 765.

20 water resource regions and 106 subregions.[1] Several indicators of the presures on the ten western water resources regions are presented in the following three tables. Table 3-3 indicates the relation between total water use, defined as the sum of instream needs and offstream consumption, and total stream flow under average and dry year conditions; table 3-4 indicates the relation between offstream water consumption and total stream flow in an average year; table 3-5 indicates groundwater mining as a percentage of total annual offstream water consumption in an average year.[2]

Surface Water

Based on the Second National Water Assessment data for average year conditions, total water use exceeds stream flows in twenty-four subregions

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[1] The regions and subregions are defined according to drainage basins and no combination of these conforms exactly to the boundaries of the seventeen western states. Ten of these regions, which are divided into fifty-three subregions, include almost all of the area of the western states. But they also include three subregions which are either totally or largely within the eastern states and another five which include some parts of the East. For the purposes of this section, however, there is little distortion introduced by using all ten western water resource regions as a proxy for the seventeen western states. The lands that are not common to both geographical groups are relatively insignificant in terms of irrigation, water use, and water supply problems.

[2] The Second National Water Assessment quantifies minimum streamflow levels for fish and wildlife population maintenance and for navigation. Instream need for a water resource subregion is calculated as the flow at the discharge point of the subregion required to satisfy the higher of the fish and wildlife or the navigational needs. In all subregions, the fish and wildlife use is the dominant instream flow use. (U.S. Water Resources Council, *Second National Water Assessment*, vol. 1, p. 42).

Offstream consumption is estimated as the total water that would have been consumed or lost assuming a demand based on 1975 levels of activity. The level of demand varies depending on the precipitation assumptions. Average precipitation levels are those that will be equaled or exceeded 50 percent of the time. Dry year precipitation levels are those that will be equaled or exceeded 80 percent of the time. The Assessment estimates only irrigation and steam electric uses differently according to the dryness of the year.

Groundwater mining or overdraft is the portion of groundwater withdrawals that exceed recharge.

Streamflow is an estimate of surface freshwater discharge rates in the absence of offstream withdrawals at the outflow point of the subregions.

Table 3-3. Total Water Use as a Percentage of Stream Flow in Average and Dry Years*

Region Number	Subregion Number	Name	Average Year	Dry Year
09		SOURIS-RED-RAINY	62	110
	01	Souris-Red-Rainy	62	110
10		MISSOURI	87	120
	01	Missouri-Milk-Saskatchewan	82	105
	02	Missouri-Marias	82	104
	03	Missouri-Musselshell	81	102
	04	Yellowstone	96	117
	05	Western Dakotas	84	108
	06	Eastern Dakotas	82	102
	07	North and South Platte	140	160
	08	Niobrara-Platte-Loup	103	122
	09	Middle Missouri	91	107
	10	Kansas	123	191
	11	Lower Missouri	87	120
11		ARKANSAS-WHITE-RED	83	138
	01	Upper White	84	126
	02	Upper Arkansas	134	175
	03	Arkansas-Cimarron	114	243
	04	Lower Arkansas	83	152
	05	Canadian	122	261
	06	Red-Washita	129	180
	07	Red-Sulphur	83	133
12		TEXAS-GULF	101	197
	01	Sabine-Neches	85	163
	02	Trinity-Galveston Bay	89	176
	03	Brazos	142	327
	04	Colorado (Texas)	119	188
	05	Nueces-Texas Coastal	96	183
13		RIO GRANDE	136	180
	01	Rio Grande Headwaters	110	159
	02	Middle Rio Grande	140	165
	03	Rio Grande-Pecos	148	176
	04	Upper Pecos	144	177
	05	Lower Rio Grande	136	180
14		UPPER COLORADO	84	112
	01	Green-White-Yampa	87	114
	02	Colorado-Gunnison	80	106
	03	Colorado-San Juan	84	112
15		LOWER COLORADO	225	239
	01	Little Colorado	80	103
	02	Lower Colorado Main Stem	225	239
	03	Gila	304	315
16		GREAT BASIN	125	158
	01	Bear-Great Salt Lake	102	125
	02	Sevier Lake	186	204
	03	Humboldt-Tonopah Desert	177	222
	04	Central Lahontan	116	165
17		PACIFIC NORTHWEST	84	102
	01	Clark Fork-Kootenai	62	73
	02	Upper / Middle Columbia	79	94
	03	Upper / Central Snake	91	119
	04	Lower Snake	78	96
	05	Coast-Lower Columbia	85	102
	06	Puget Sound	81	96
	07	Oregon Closed Basin	101	161
18		CALIFORNIA	82	113
	01	Klamath-North Coastal	65	95
	02	Sacramento-Lahontan	76	106
	03	San Joaquin-Tulare	109	131
	04	San Francisco Bay	91	132
	05	Central California Coast	83	169
	06	Southern California	107	116
	07	Lahontan-South	243	290

Source: U.S. Water Resources Council, The Nation's Water Resources: The Second National Water Assessment, 1978, Vol. 2, Appendix II, tables II-3 and II-4, Appendix IV, table IV-2.

*Total water use includes instream use and offstream consumption.

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Table 3-4. Offstream Water Consumption as a Percent of Total Stream Flow in an Average Year

Region Number	Subregion Number	Name	Offstream Consumption as a % of Stream Flow
09		SOURIS-RED-RAINY	2
	01	Souris-Red-Rainy	2
10		MISSOURI	27
	01	Missouri-Milk-Saskatchewan	23
	02	Missouri-Marias	22
	03	Missouri-Musselshell	21
	04	Yellowstone	21
	05	Western Dakotas	24
	06	Eastern Dakotas	22
	07	North and South Platte	85
	08	Niobrara-Platte-Loup	69
	09	Middle Missouri	32
	10	Kansas	63
	11	Lower Missouri	27
11		ARKANSAS-WHITE-RED	12
	01	Upper White	1
	02	Upper Arkansas	85
	03	Arkansas-Cimarron	56
	04	Lower Arkansas	19
	05	Canadian	62
	06	Red-Washita	68
	07	Red-Sulphur	12
12		TEXAS-GULF	33
	01	Sabine-Neches	5
	02	Trinity-Galveston Bay	18
	03	Brazos	84
	04	Colorado (Texas)	82
	05	Nueces-Texas Coastal	26
13		RIO GRANDE	88
	01	Rio Grande Headwaters	69
	02	Middle Rio Grande	96
	03	Rio Grande-Pecos	102
	04	Upper Pecos	94
	05	Lower Rio Grande	88
14		UPPER COLORADO	20
	01	Green-White-Yampa	22
	02	Colorado-Gunnison	17
	03	Colorado-San Juan	20
15		LOWER COLORADO	114
	01	Little Colorado	21
	02	Lower Colorado Main Stem	114
	03	Gila	254
16		GREAT BASIN	66
	01	Bear-Great Salt Lake	44
	02	Sevier Lake	127
	03	Humboldt-Tonopah Desert	117
	04	Central Lahontan	56
17		PACIFIC NORTHWEST	4
	01	Clark Fork-Kootenai	2
	02	Upper / Middle Columbia	8
	03	Upper / Central Snake	33
	04	Lower Snake	16
	05	Coast-Lower Columbia	3
	06	Puget Sound	<1
	07	Oregon Closed Basin	41
18		CALIFORNIA	37
	01	Klamath-North Coastal	3
	02	Sacramento-Lahontan	28
	03	San Joaquin-Tulare	89
	04	San Francisco Bay	24
	05	Central California Coast	37
	06	Southern California	101
	07	Lahontan-South	100

Source: U.S. Water Resources Council, Second National Water Assessment, vol. 3, appendix II, table II-3.

Table 3-5. Groundwater Mining as a Percentage of Annual Offstream Water Consumption in an Average Year

Region Number	Subregion Number*	Name	Groundwater Mining as a % of Annual Offstream Consumption
10		MISSOURI	17
	03	Missouri-Musselshell	1
	05	Western Dakotas	2
	06	Eastern Dakotas	7
	07	North and South Platte	13
	08	Niobrara-Platte-Loup	13
	09	Middle Missouri	16
	10	Kansas	41
	11	Lower Missouri	5
11		ARKANSAS-WHITE-RED	68
	01	Upper White	2
	02	Upper Arkansas	3
	03	Arkansas-Cimarron **	100
	04	Lower Arkansas	2
	05	Canadian	85
	06	Red-Washita	55
	07	Red-Sulphur	1
12		TEXAS-GULF	50
	01	Sabine-Neches	8
	02	Trinity-Galveston Bay	19
	03	Brazos	78
	04	Colorado (Texas)	38
	05	Nueces-Texas Coastal	26
13		RIO GRANDE	16
	02	Middle Rio Grande	21
	03	Rio Grande-Pecos	46
	04	Upper Pecos	16
	05	Lower Rio Grande	1
15		LOWER COLORADO	53
	01	Little Colorado	7
	02	Lower Colorado Main Stem	27
	03	Gila	61
16		GREAT BASIN	16
	01	Bear-Great Salt Lake	3
	02	Sevier Lake	40
	03	Humboldt-Tonopah Desert	27
	04	Central Lahontan	3
17		PACIFIC NORTHWEST	5
	01	Clark Fork-Kootenai	2
	02	Upper / Middle Columbia	8
	03	Upper / Central Snake	4
	04	Lower Snake	7
	05	Coast-Lower Columbia	2
	07	Oregon Closed Basin	2
18		CALIFORNIA	8
	02	Sacramento-Lahontan	4
	03	San Joaquin-Tulare	10
	05	Central California Coast	10
	06	Southern California	8
	07	Lahontan-South	43

Source: U.S. Water Resources Council, The Nation's Water Resources: The Second National Assessment, Vol. 3, Appendix II, Table II-4.

*Includes only subregions with percentages of 0.5 or above.

**The assessment shows groundwater mining at 103 percent of offstream consumption. Since the theoretical limit should be 100 percent, this is the figure used here.

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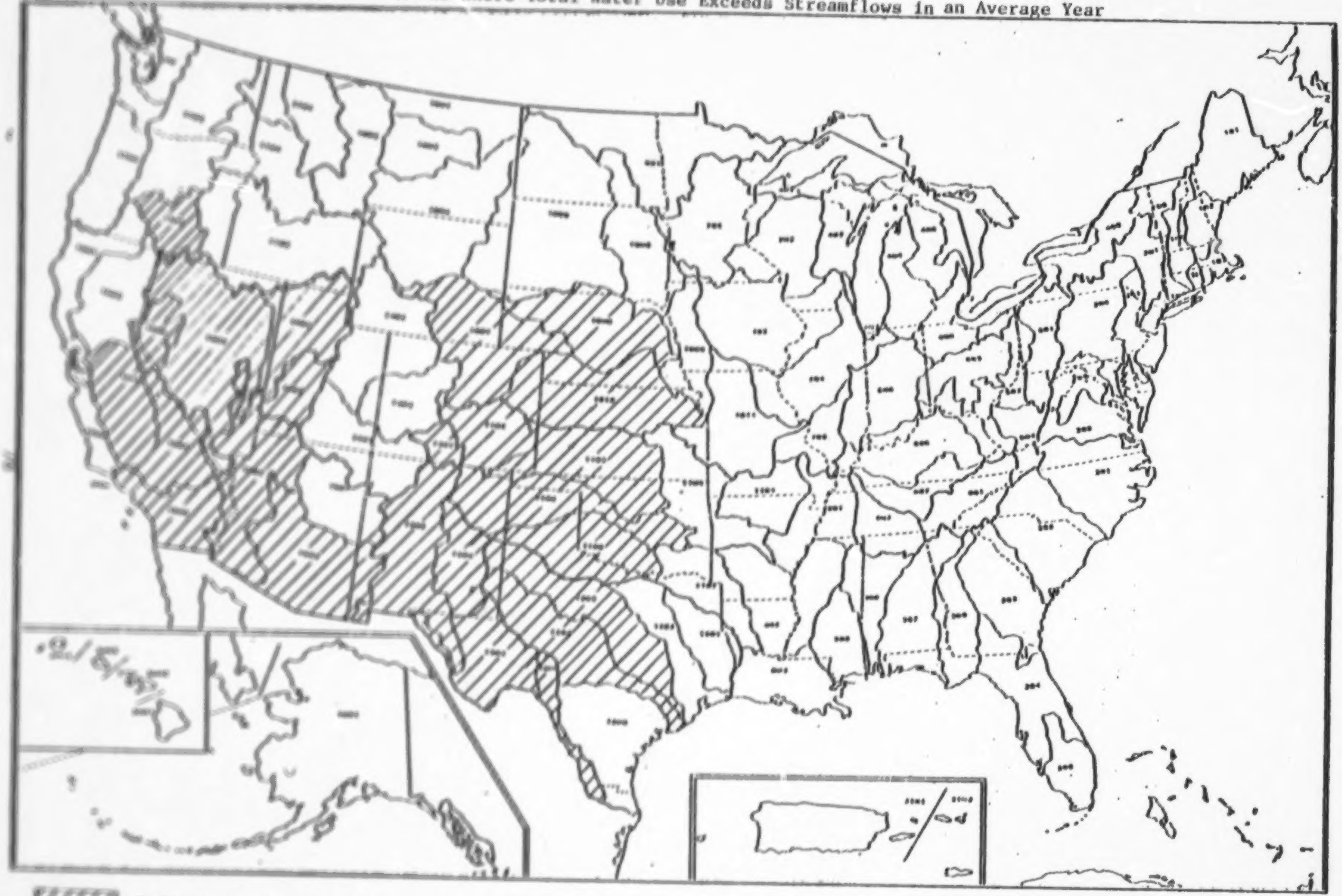
(indicated in figure 3-1), which account for about 66 percent of the West's irrigated land. Furthermore, in most of the other twenty-nine subregions there is little slack between stream flows and total water use. Total use is less than 75 percent of stream flows in only three subregions and these are areas with relatively poor agricultural potential.

In a year of below average rainfall, the imbalance between supplies and needs is more intense and widespread. The shortfall results not only from reduced supplies but also from higher demand, especially for irrigation water. In a dry year, water total use exceeds stream flows in forty-eight of the fifty-three subregions (see table 3-3). Four of the exceptions are in the humid Pacific Northwest region and the other is the northernmost subregion of the California region. The magnitude of the supply shortfalls are particularly striking. In twenty-six of the subregions, water use exceeds stream flows by more than 50 percent and in eight of the subregions use is more than twice dry-year stream flows.

As noted above, total water use includes an estimate of instream needs. Instream water flows can serve a number of purposes including maintaining fish and wildlife populations, outdoor recreation, navigation, hydroelectric generation, waste assimilation, and maintaining aquatic and riparian vegetation. While the second assessment estimates of instream needs reflect only the minimum flow needed to maintain fish and wildlife, a comparison of the average year percentages in tables 3-3 and 3-4 suggests the considerable importance of instream uses to the degree of water scarcity. In thirty-three of the subregions, insteam flow requirements are more than half of total water use. Offstream water consumption exceeds total stream flow in an average year in only six subregions.

Although there is no consensus as to how much water should be allocated to instream uses such as fish and wildlife, this does not mean that including

Figure 3-1. Water Resource Subregions Where Total Water Use Exceeds Streamflows in an Average Year



▨ Indicates subregions where total water use exceeds total streamflow in an average year.

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these uses in estimating total water use overstates the degree of water scarcity. There is also no general agreement as to the amount of water that should be allocated ot irrigation or any other use. Society's valuation of instream flows has increased in recent years and it may increase further in the future. Even though these uses do not compete for water in the marketplace, society must take them into account if scarce supplies are to be efficiently allocated among alternative uses.

Groundwater

The quantity of water stored in the ground far exceeds that available in streams, lakes, and ponds.[1] Even though it will be too expensive to ever utilize most of the groundwater, the quantities economically available for use are vast. These stocks provide both a valuable source for expanding water use as well as a supplement to surface water resources during unusually dry periods. Groundwater use can reduce the risk of substantial loss in a dry year, the need for costly surface storage, and the evaporation losses that result when surface storage is used. However, this is not the use to which western groundwater stocks generally have been employed. Groundwater has become the principal source of supply in many areas, not simply a dry year supplement. Consequently enormous quantities of water are mined from western aquifers even in the wettest of years.

Mining, the net difference between extractions and recharge, exceeds 20 billion gallons per day of 22.4 million acre-feet per year in an average year. Just within the Texas and Oklahoma High Plains, annual groundwater mining is 14 million acre-feet, equivalent to the average annual flow of the Colorado River.[1] The annual mining from western aquifers is equivalent to 40 percent of groundwater withdrawals for irrigation in 1975 (see table 3-2) and is sufficient to irrigate 10.7 million acres based on average consumption levels.[2]

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[1] Although the discussion differentiates between ground and surface waters, in fact the distinction between these two sources of supply is not always clear. For example, the Second National Water Assessment reports that, "About 30 percent of the Nation's streamflow, in an average year, is supplied by ground water that emerges as natural springs and other seepage. In turn, seepage from streams, rivers, canals, and reservoirs is a source of ground-water recharge. Most of the flow in many smaller streams comes from ground water during the low-flow months. In years of below normal precipitation, all the streamflow during low stage may be ground water. Ground water, therefore, is important to the continuity of streamflow." U.S. Water Resources Council, _Second National Water Assessment_, vol. 1: Summary, p. 10.

Groundwater mining is equivalent to 10 percent or more of annual offstream consumption in twenty-one water resource subregions (see figure 3-3). Not surprisingly, there is a close parallel between these subregions and the twenty-four subregions where average year water use exceeds stream flow; seventeen subregions belong to both groups and these seventeen account for about 86 percent of the total western groundwater depletions. Groundwater mining is 30 percent or more of offstream consumption in eleven subregions and 50 percent or more in five subregions. The five subregions with the highest rates of groundwater mining include most of the High Plains of Texas, Oklahoma, New Mexico, Colorado, and Kansas and Arizona's principal agricultural areas. These five subregions alone account for 20 percent of the West's irrigated lands.

Despite the enormous quantities of water involved, groundwater mining is not a threat to exhaust the physical supply of water stored in any of the water resource regions or subregions during the foreseeable future.[3]

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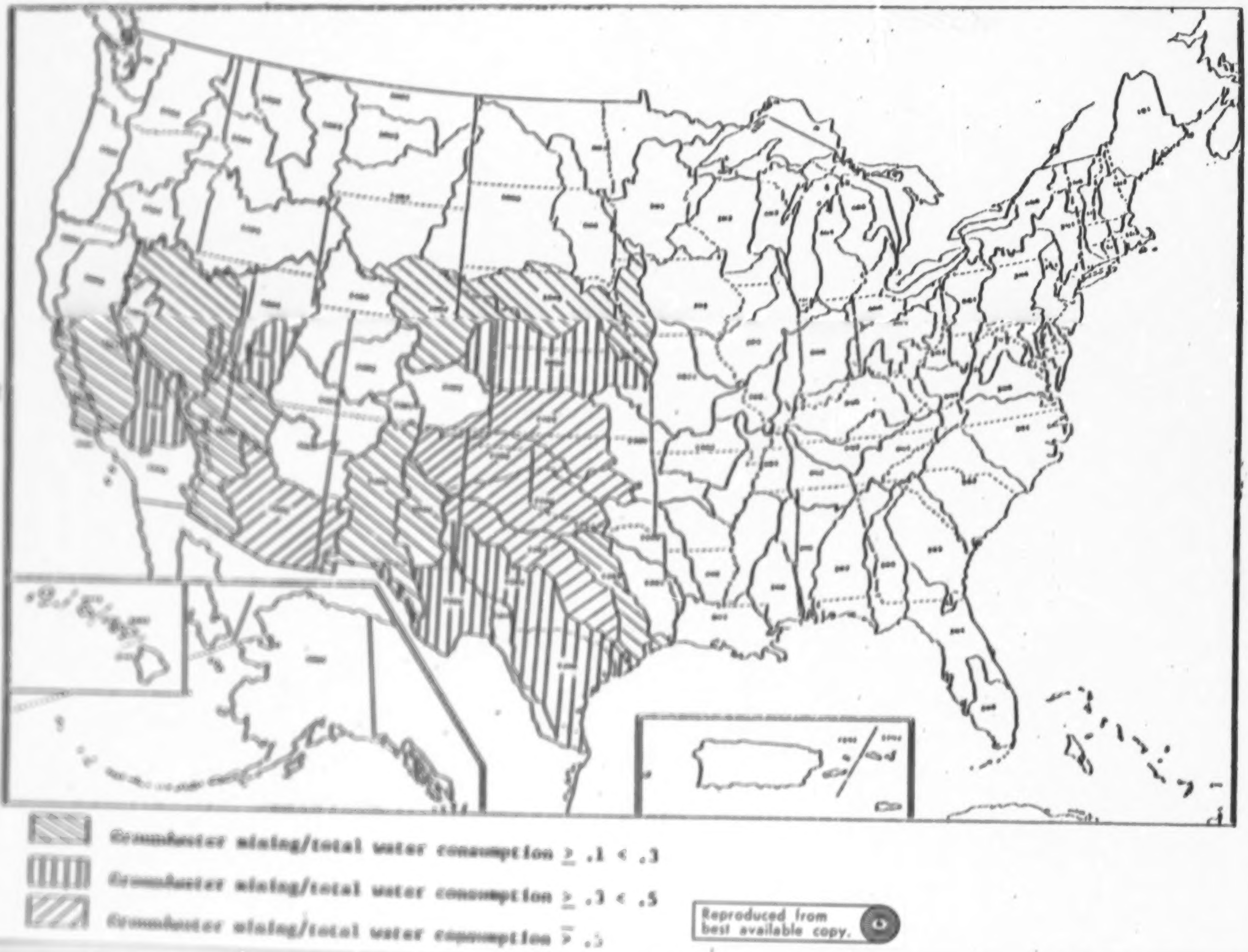
[1] U.S. Water Resources Council, *Second National Water Assessment*, vol. 1, p. 18.

[2] Based on the National Future estimates of the *Second National Water Assessment* (vol. 2, Part III, pp. 57 and 62), which indicate 86.4 billion gallons per day or 96.8 million acre-feet per year were consumed to irrigate 45.3 million acres, average consumption was 2.1 acre-feet of water per irrigated acre.

[3] The economic supply of water for relatively low value uses such as irrigation is threatened, however, in several of the West's important agricultural areas. The relations between groundwater mining and pumping depths and well yields in the Texas High Plains are discussed in the following subsection; the relations between water costs and the profitability of irrigation are examined in section 3.

Figure 3-2. Subregions Where Groundwater Mining is at Least 10 Percent of Offstream Water Consumption in an Average Year


▨ Groundwater mining/total water consumption ≥ .1 < .3
▥ Groundwater mining/total water consumption ≥ .3 < .5
▨ Groundwater mining/total water consumption ≥ .5

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Groundwater stocks are large, and only in the California region does annual mining for an entire region approach 1 percent of available storage.[1] The comparable percentages for the other water resource regions are 0.4 for the Arkansas-Red-White, 0.2 for the Missouri, and 0.1 or less for all other regions. The percentages for individual subregions may exceed these regional levels, but mining is 1 percent or more of available storage in only four subregions--the North and South Platte River basin (subregion 1007) with 2.0 percent, the San Joaquin valley (subregion 1802) with 1.8 percent, the central California coastal area (subregion 1805) with 1.0 percent, and the Arikaree-Republican River area of northern Kansas and southern Nebraska (subregion 1010) with 1.0 percent. The comparable percentages for the subregions which include the High Plains are generally between 0.6 and 1.0.

Water Supply Trends in the Texas High Plains

Aggregate data for regions as large and diverse as the water resource subregions are inadequate for analyzing the implications for irrigated agriculture. The subregional data on groundwater mining as a percentage of available storage understate the problem facing many irrigators since much of the water included as available storage underlies areas with low agricultural potential or is located at depths and in quantities that make it too costly for use in irrigation. Furthermore, seemingly modest reductions in the groundwater stocks of a large water resource subregion obscure the devastation experienced by particular areas when the reductions are localized. While there are insufficient data for a detailed analysis for the West of irrigation water supplies and the impacts of current usage on future supplies, studies of the Texas High Plains suggest the problems many farmers, local communities, and regional economies may encounter.

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[1] Available storage is that portion of total groundwater storage which can be tapped with conventional wells, methods, and machinery.

A series of county studies by the Texas Department of Water Resources illustrates the impacts irrigation may have on future water resources in one of the West's principal irrigated areas, the southern High Plains. In these county studies the volume of water in storage, the saturated thickness of the aquifer, and pumping rates and lifts are estimated for 1974 and projected for 10-year intervals from 1980 to 2020. The projections are based on observed water use and precipitation levels between 1960 and 1972 with adjustments over time to allow for the effects of depletion on well yields.

A twenty-four county region in the southern High Plains of Texas is used to illustrate the impacts of groundwater mining on future water availability.[1] Irrigation has been essential to this region's growth and is important to its continued prosperity.

Aggregate farm income of these twenty-four counties exceeded $1.3 billion in the mid-1970s. Although irrigation's contribution to this income is unknown, it clearly was sizable. For example, virtually all the corn, about 80 percent of the sorghum and wheat, and 89 percent of the cotton production of these counties were grown with irrigation.[2]

The water and acreage data for twenty-four High Plains counties are aggregated and summarized in tables 3-6, 3-7, and 3-8. The Ogallala is the principal

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[1] The twenty-four counties are Armstrong, Bailey, Carson, Castro, Parmer, Lamb, Hale, Gaines, Gray, Randall, Swisher, Dawson, Borden, Lynn, Garza, Terry, Yoakum, Cochran, Lubbock, Hockley, Deaf Smith, Briscoe, Floyd, and Crosby. These counties, which comprise a contiguous area of the southern Texas High Plains, were the only ones for which analytical studies of the underlying Ogallala aquifer were available. Unless otherwise stated all the information in this section on groundwater in the Texas High Plains and the economies of these twenty-four counties is from the series of studies published by the Texas Department of Water Resources. These reports, which were published between February 1976 and March 1979, are titled *Analytical Study of the Ogallala Aquifer in ———— County, Texas: Projections of Saturated Thickness, Volume of Water in Storage, Pumpage Rates, Pumping Lifts, and Well Yields*.

[2] These data are based on the following publications of the Texas Crop and Livestock Reporting Service: Wheat = *1976 Texas Small Grains Statistics*, p. 13, cotton = *1976 Texas Cotton Statistics*, p. 18; sorghum = *1975 Texas Field Crop Statistics*, pp. 67 and 71. These sources do not distinguish between irrigated and dryland corn.

Table 3-6. Groundwater Storage and Annual Pumping in 1974, 2000, and 2020 for a 24 County Area in the Texas High Plains (millions acre-feet)

	Volume of Groundwater in Storage[a]	Annual Water Pumpage
1974[b]	145.9	4.1
2000	85.2	3.0
2020	52.3	2.2

Source: Texas Department of Water Resources, *Analytical Study of the Ogallala Aquifer in ———— County, Texas*. (Note 1, p. 23 lists the counties included in these totals.)

[a] These are based on estimates of the total amount of water in storage. The quantities that can be economically recovered for use are significantly less than the total amount in storage.

[b] Several of the county studies from which these estimates are drawn list 1975 rather than 1974 as the base year.

Table 3-7. Surface Area Grouped by the Saturated Thickness of the Underlying Aquifer for a 24 County Area in the Texas High Plains (1,000 acres)

	Surface Area Grouped by the Saturated Thickness of the Aquifer			
Saturated Thickness	0-50 ft.	50-100 ft.	100-150 ft.	150+ ft.
1974[a]	4,636	3,471	1,083	1,787
2000	7,363	3,231	820	201
2020	9,830	1,852	121	73

Source: Texas Department of Water Resources, *Analytical Study of the Ogallala Aquifer in ———— County, Texas*. (Note 1, p. 23 lists the counties included in these totals.)

[a] Several of the county studies from which these estimates are drawn list 1975 rather 1974 as the base year.

Table 3-8. Surface Area Corresponding to Alternative Pumping Lift Intervals for a 24 County Area in the Texas High Plains for the Years 1974, 2000, and 2020 (1,000 acres)

Pumping Lift Intervals	1974[a]	2000	2020
0-25 ft.	145	143	143
25-50 ft.	374	354	354
50-75 ft.	389	383	383
75-100 ft.	548	525	525
100-125 ft.	829	780	783
125-150 ft.	1,592	1,319	1,313
150-175 ft.	1,553	1,431	1,403
175-200 ft.	1,338	1,367	1,345
200-225 ft.	1,249	1,066	1,078
225-250 ft.	1,091	552	525
250-275 ft.	839	590	571
275-300 ft.	531	776	669
300-325 ft.	360	748	644
325-350 ft.	293	488	530
350-375 ft.	204	383	445
375-400 ft.	178	240	342
400-425 ft.	110	183	181
425-450 ft.	137	138	138
≥ 450 ft.	82	350	473

Source: Texas Department of Water Resources, Analytical Study of the Ogallala Aquifer in ———— County, Texas. (Note 1, p. 23 lists the counties included in these totals.

[a] Several of the county studies from which these estimates are drawn list 1975 rather than 1974 as the base year.

source of irrigation water for these counties, and as the data in these tables indicate, the future prosperity of the region is threatened by the depletion of the aquifer. Annual pumping from the aquifer underlying these counties is projected to decline from 4.1 million acre-feet in 1974, to 3.0 million in 2000, and 2.2 million in 2020, and the water in storage is projected to fall from 145.9 million acre-feet in 1974 to 52.3 million acre-feet in 2020. Thus, even with the 46 percent decline in pumping, the projections imply that annual pumping will rise to nearly 4.2 percent of storage by 2020 compared to 2.8 percent in 1974.

Groundwater depletion is not new to this area. It is estimated that the volume of water stored in the Ogallala south of the Canadian River declined by about 100 million acre-feet or over 40 percent from 1937 to 1972.[1] While the estimates of past and projected groundwater use suggest the levels may have peaked about the mid-1970s in this region, pumping and groundwater mining as a percentage of water in storage are expected to continue to increase out to 2020.

Table 3-7 and 3-8 indicate the projected changes in the saturated thickness of the aquifer and the pumping depths for 1974, 2000, and 2020 in these twenty-four High Plains counties. These features are important determinants of water costs. Saturated thickness is directly related to well yields while pumping depth is the primary determinant of the energy required to lift water to the surface.[2] The capital costs associated with drilling and the optimal size of the power source and well are also related to the saturated thickness and pumping depth.

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[1] U.S. Department of Interior, Bureau of Reclamation, West Texas and Eastern New Mexico Import Project, Reconnaissance Report, June 1973, pp. 18-19.

[2] The pumping depth or lift is the distance from the surface to the water level in an operational well. It is equal to the depth to the static water level plus the drawdown due to pumping.

In 1974 almost 3.7 million acres overlaid sections of the aquifer with a saturated thickness of 100 feet or more, the thickness generally required for well yields exceeding 1,000 gallons per minute. In comparison, the saturated thickness of the aquifer is projected to be 100 feet or more for only about 1 million acres by the turn of the century and 196,000 acres by 2020. On the other hand, the acreage overlying saturated sections of the aquifer of 50 feet or less is projected to rise from 4.6 million in 1974, to 7.6 million in 2000, and 9.9 million in 2020. These projected declines in the saturated thickness of the aquifer are particularly serious since they imply even sharper reductions in well yields. For example, a decline in the saturated thickness from 100 to 40 feet is apt to reduce the yield of a well in this region from 1,000 to 250 gallons per minute even when adjustments in the well and pump are made to reflect changes in the aquifer.[1] Since these well yield estimates are based on capability with optimal equipment, the actual reductions in well yields experienced by a typical farmer are likely to be greater. But even under the best circumstances, this 60 feet decline in saturated thickness reduces the potential irrigable acreage for this well by 75 percent. In practice the impacts of lower well yields on actual acreage irrigated have been cushioned by

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[1] The actual relation between well yields and saturated thickness varies depending on the physical composition of the aquifer. For example, saturated portions comprised largely of silt and clay will restrict well yields much more than will a sandy composition. For a well penetrating the total saturated section of the aquifer and sized to produce the maximum water yield, the Texas Department of Water Resources offers the following general guide relating well yield to saturated thickness in the Texas High Plains:

Saturated Thickness (feet)	Well Yield (gallons per minute)
Less than 20	Less than 100
20-40	100-250
40-60	250-500
60-80	500-800
80-100	800-1,000
More than 100	More than 1,000

Source: P. 9 of the county reports referenced in note 1, p. 23.

pumping longer hours, switching to crops with lower water requirements, or adopting other water conserving practices.

The changes in pumping lifts implied by the projected aquifer depletions are indicated in table 3-8. The most striking changes are the increases in the acreage with relatively high pumping lifts. For example, the lands with lifts of 300 feet or more are projected to rise from 1.4 million acres in 1974, to 2.5 million acres in 2000, and 2.8 million acres in 2020 while lands with lifts of 400 feet or more are projected to double by the end of this century. While the lands with pumping depths of 100 feet or less are projected to decline by only 51,000 acres by both 2000 and 2020, even in 1974 these lands accounted for only about 12 percent of the total. In comparison lands with lifts of 300 feet or more are projected to rise from 11 to 23 percent of the total by 2020.

Groundwater mining has widely differing impacts even within an area that is relatively homogeneous with respect to most factors affecting agricultural production. Despite being linked to a common aquifer, groundwater is very unevenly distributed within and among the southern High Plains counties. Also, depending on the configuration of the aquifer and its physical composition, individual lands are affected very differently by mining. For example, water table declines in the southern High Plains of Texas due to groundwater pumping from 1948 to 1967 varied from less than 20 feet to more than 120.[1] Consequently, while many farmers already have been forced to abandon irrigation, others still have relatively secure futures. (The economic implications of declining well yields and rising pumping lifts are considered in section 5 of this study.)

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[1] Bureau of Reclamation, West Texas and Eastern New Mexico Import Project, p. 18.

The groundwater situation in the southern High Plains is illustrative but not representative of the problems confronting many other irrigated areas. Indeed, the low rates of natural recharge, the high dependence on groundwater, and the extent and duration of the demands on groundwater all suggest that the water situation in the southern High Plains is unusually serious. On the other hand, in comparison with the arid west, irrigation requires less water and dryland farming is an alternative in the High Plains. Moreover, pumping depths in the southern Ogallala are not high compared to those of some other irrigated areas. For example, the water tables in the southern portion of the Ogallala are often closer to the surface (although with less saturated thickness) than those of the Ogallala north of the Canadian River.[1] In short, there are wide differences in the impacts of groundwater mining on individual farmers both among and between irrigated areas.

COMPETITION FOR WESTERN WATER

While irrigation continues to dominate the use of western water, other water demands are growing more rapidly. From 1960 to 1975, total fresh water consumed in western irrigation grew at only one-half the rate for all other uses combined (see table 3-9). Only in the Northern Plains did the rate of growth of water consumption for irrigation exceed the rate for all other uses. Nevertheless, other water uses accounted for only 8.6 percent of total western consumption in 1975, an increase of only 2 percent over the fifteen years. Only in the Southern Plains regions does irrigation account for less than 90 percent of total freshwater consumption.

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[1] In four Texas counties north of the Canadian River for which comparable studies of the aquifer are available, 42.6 percent of the land had pumping lifts of 300 feet or more in 1974. This compares to only 11.5 percent of the land with such lifts in the twenty-four High Plains counties. On the other hand, 87 percent of the land overlying the Ogalalla in these four northern counties had a saturated thickness of 150 feet or more compared to only 6 percent of the land in the southern High Plains.

Water Consumption Projections

Future change in irrigated acreage will vary widely depending in large part on the relation between the supply and demand for water in a particular area. Although water is transportable, the costs of doing so are high in relation to its value in agriculture. Consequently, irrigators in a given area must rely largely on the water currently available either naturally or through water importation structures already in place. This suggests that some disaggregation of the West according to water scarcity would be useful for forecasting likely changes in irrigation.

Although the Second National Water Assessment projects water use for each of the fifty-three western water resource subregions, it is nearly as instructive and conceptually much simpler to differentiate between just two areas--a water-scarce area and the rest of the West. The water-scarce area, consisting of twenty subregions, is indicated in figure 3-3. All twenty of these subregions, which are identified in the notes to table 3-10 as well as in figure 3-3, have either high ratios of water requirements to stream flows or high ratios of groundwater mining to consumption, and in most of these subregions both conditions prevail. Consequently, satisfying the growth of nonagricultural water demands in this region will require with increasing frequency diverting water out of irrigation, which accounts for nearly 92 percent of the area's water consumption. Furthermore, the area's heavy dependence on new renewable water sources suggests total water use may decline by the year 2000 in some of these subregions.

Table 3-9. Freshwater Consumption by Western Farm Production Region,
1960, 1965, 1970, and 1975
(millions of gallons per day)

	1960	1965	1970	1975
Northern Plains:				
Irrigation	2.866	4,730	6,060	9,930
All Other	424	567	659	705
Total	3,290	5,297	6,719	10,635
"All Other" as % of Total	12.9	10.7	9.8	6.6
Southern Plains:				
Irrigation	6,390	11,260	8,670	11,820
All Other	960	1,388	1,804	2,183
Total	7,350	12,648	10,474	14,003
"All Other" as % of Total	13.1	11.0	17.2	15.6
Mountain:				
Irrigation	20,960	25,500	28,200	25,000
All Other	840	935	1,245	1,643
Total	21,800	26,435	29,445	26,643
"All Other" as % of Total	3.9	3.5	4.2	6.2
Pacific:				
Irrigation	18,100	19,400	24,500	26,200
All Other	1,200	1,877	2,262	2,356
Total	19,300	21,277	26,762	28,556
"All Other" as % of Total	6.2	8.8	8.5	8.3
Western States:				
Irrigation	48,316	60,890	67,430	72,950
All Other	3,424	4,767	5,970	6,887
Total	51,740	65,657	73,400	79,837
"All Other" as % of Total	6.6	7.3	8.1	8.6

Source: U.S. Geological Survey, Circulars 456, 556, 676, and 765.

Figure 3-3. Twenty Water Resource Subregions with Serious Water Supply Problems

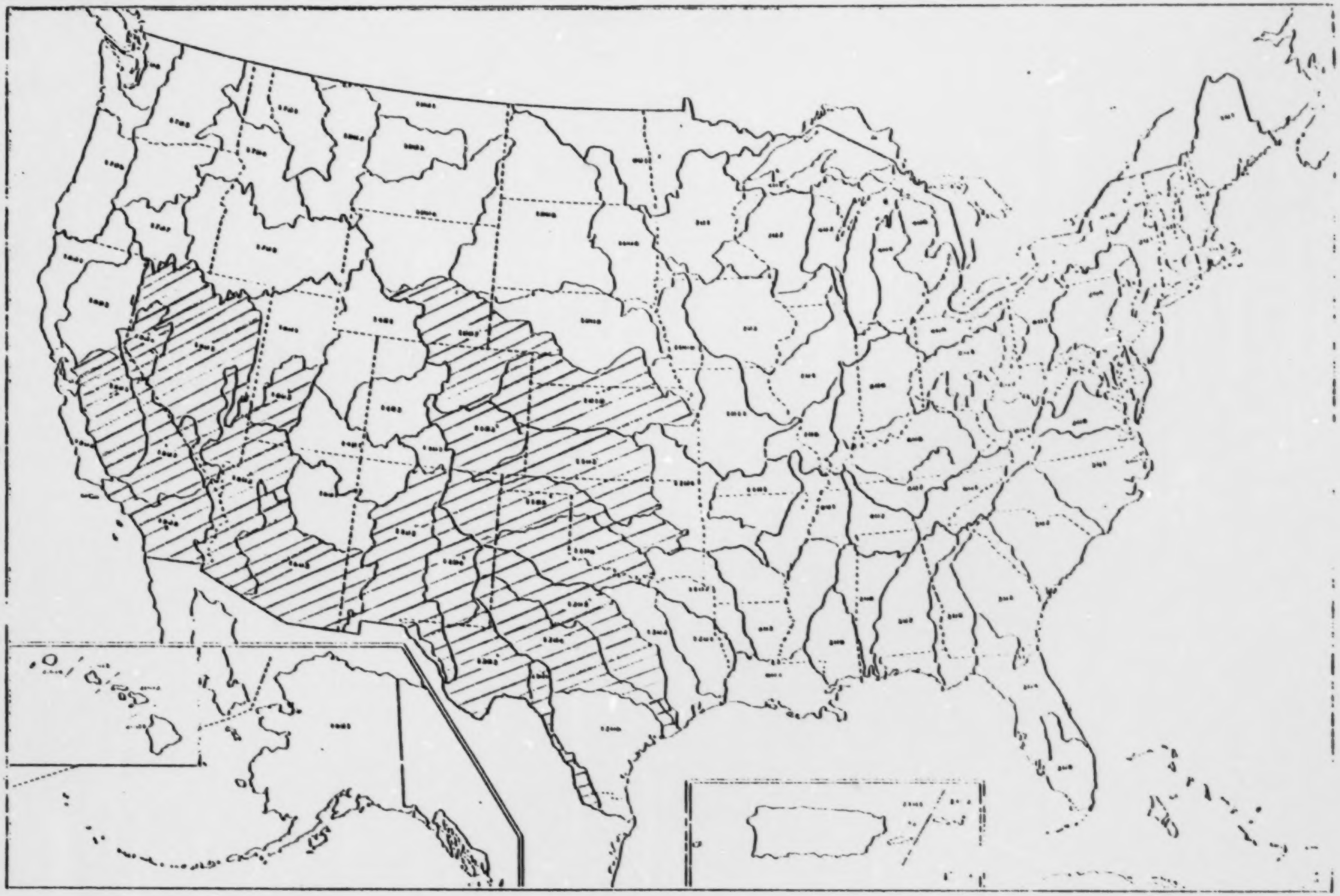

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Table 3-10. Annual Water Consumption for Offstream Uses: National Future Average Year Estimates, 1975, 1985, and 2000

(millions of gallons per day)

	1975	1985	2000
20 Water-Scarce Subregions[a]			
Irrigation	47,815	46,387	45,124
All other	4,339	5,190	6,747
Total	52,154	51,577	51,871
33 Other Subregions			
Irrigation	31,470	38,508	38,809
All other	4,888	6,720	9,977
Total	36,358	45,228	48,786
Total West (water resource regions 9 to 18)			
Irrigation	79,285	84,895	83,933
All other	9,227	11,910	16,724
Total	88,512	96,805	100,657

[a] This water-scarce area includes the following water resource subregions: 1007, 1010, 1102, 1103, 1105, 1106, 1203, 1204, 1302, 1303, 1304, 1305, 1502, 1503, 1602, 1603, 1604, 1803, 1806, and 1807.

Source: U.S. Water Resources Council, The Nation's Water Resources, The Second National Water Assessment, vol. 3, Appendix II, table II-4.

The Assessment's National Future (NF) average year projections of freshwater consumption for irrigation and other uses are presented in table 3-10.[1] Within the water-scarce area total water consumption is projected to decline slightly (0.5 percent) over the last quarter of the century. Greater changes, however, are expected in the allocation of the water. Irrigation water consumption is projected to decline by 3 percent from 1975 to 1985 and by an additional 3 percent from 1985 to 2000. In contrast, consumption for all other purposes is projected to rise by 55 percent. These projections illustrate an important implication of the dominance of irrigation in western water use--large percentage increases in water allocations to other uses can be accommodated with relatively small percentage reductions in irrigation water consumption.

In contrast to the outlook in the twenty water-scarce subregions, there are opportunities for expanding both total and irrigation water consumption in the rest of the West. Indeed, the Second National Water Assessment projects irrigation water consumption will increase a total of 22 percent between 1975 and 1985 in the other thirty-three subregions. However, no significant further expansion of water consumption for irrigation is projected for this region over the last fifteen years of the century. The twenty-five year projections for these thirty-three subregions suggest that water consumption will rise 34 percent and consumption for purposes other than irrigation will more than double.

Total western water consumption is projected to rise nearly 14 percent from 1975 to 2000 with irrigation accounting for 38 percent of the increase.

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[1] The Second National Water Assessment provides four estimates of off-stream consumption for each of the years--1975, 1985, and 2000. These are the National Future (NF) and State/Regional Future (SRF) projections for both dry and average year conditions.

However, the implied annual water consumption growth rates are only 0.2 percent for irrigation and 2.4 percent for all other uses.

The Assessment's National Future projections of irrigated acreage closely parallel their irrigation water consumption projections with allowance for only modest reductions in the implied consumption of water per irrigated acre. From 1975 to 2000 irrigated acreage is projected to decline about 1 percent in the twenty water-scarce subregions and to rise about 26 percent in the rest of the West for a net increase of nearly 11 percent for the West as a whole. Most of the relative regional shifts are projected to occur by 1985 as irrigation in the water-scarce region is projected to decline from 57 percent of the western total as of 1975, to 52 percent by 1985, and 51 percent by 2000.[1]

Water for Energy

Development of the West's vast energy resources, especially coal and oil shale, are expected to place particularly heavy demands on western water. While the water consumption projections of the Second National Water Assessment include an allowance for steam electric production, petroleum refining, and fuels mining, there was concern that the Assessment had not taken adequate account of all likely energy developments and associated water requirements. This concern led to a supplementary study by the Aerospace Corporation.[2] The Aerospace Report (AR) accepts all the Assessment's water supply data and all the demand projections except those relating to energy. From four federally generated energy development scenarios, the AR report determines the maximum feasible limits for energy development and the associated water requirements assuming standard size plants and no special provisions to adopt water-conserving technologies. Consequently, the AR water-for-energy estimates are higher than any likely levels. In comparison to the Assessment projections presented in table 3-10, the resulting nonirrigation water consumption levels are 7 percent higher by 1985 and 39 percent higher by 2000.

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[1] The percentages are calculated from data in U.S. Water Resources Council, The Nation's Water Resources: The Second National Water Assessment, vol. 3, appendix 1, table 1-4.

[2] Aerospace Corporation, Water Related Constraints on Energy Production, Aerospace Report No. ATR-78(9409)-1, June 1978.

The AR estimates represent a 1 percent increase in total western water demand by 1985 and a 6 percent increase by 2000. Although these are only modest percentage changes, they would be localized and within the affected regions major new demands on water supplies are implied. Where demand already exceeds renewable supplies, any increase requires either compensating reductions among other users or additional groundwater mining.

The twenty water-scarce subregions account for about 47 percent of the consumption of water for energy projected for the turn of the century in the AR report. Within this area energy uses would rise to about 8 percent of total water consumption. If these projections are realized, water for energy would become particularly important in seven of these subregions.[1] Energy uses account for 19 percent of total projected water consumption within these seven subregions, and combined the seven subregions account for 72 percent of the projected water for energy within the twenty water-scarce subregions.[2] However, these seven subregions are less important in terms of their relative contribution to irrigation. In 1975 they accounted for 28 percent of the irrigated acreage in the water-scarce area and this percentage is expected to decline to 20 percent by 2000. Their contribution to total western irrigation is projected to decline from 16 percent in 1975 to 10 percent in 2000.[1]

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[1] The seven subregions are Lahonten-South (1807) and Southern California (1806) in the California region, Humboldt-Tonopah Desert (1603) and Central Lahonten (1604) in the Great Basin region, Middle Rio Grande (1302) in the Rio Grande Region, and Brazos (1203) and Colorado (1204) in the Texas Gulf region.

[2] The water consumption figures in these two paragraphs as based on data in Aerospace Corporation, Water Related Constraints on Energy Production, table 6-2.

The AR projections suggest that energy uses could become an even more important component of water consumption in some of the subregions where water currently does not pose such constraints to development. In nine of these other 33 western subregions, the combined energy uses of water account for 35 percent of total projected water use in 2000.[2] In general, however, these nine subregions do not rank among the more important irrigated areas; they are projected to account for only 13 percent of the water consumption and 8 percent of the irrigated land in these 33 subregions by 2000 and 6 percent of the water and 4 percent of the irrigated land for the West.

The water actually diverted to energy uses and away from irrigation will depend in large part on the institutions, including the legal system affecting water use. These institutions vary widely among states. The earliest irrigators start from a preferred position in any struggle for water in that they commonly own the most senior water rights. Potential new irrigators have no such legal advantage and they face a major economic disadvantage in that irrigation in general is a relatively low-value user of water. For example, water costs of $100 or more per acre-foot would be a very minor part of the total costs of mining or processing western coal while water costs of half these levels would be prohibitive for many irrigators, especially those growing relatively low-value crops. Thus, if market forces are allowed to operate, water will tend to move out of irrigation as demand starts to exceed an areas's supply. Some farmers already have found it profitable to sell their water rights, and unless they are legally constrained from doing so, many others are likely to follow suit. (Section 4 of this study examines the institutional factors affecting the use of western water.)

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[1] U.S. Water Resources Council, The Nation's Water Resources: The Second National Water Assessment, vol. 3, appendix 1, table 1-4.

[2] The nine subregions are Western Dakotas (1005), Middle Missouri (1009), and Lower Missouri (1001) of the Missouri region, Upper White (1101), Yellowstone (1104), North and South Platte (1107) of the Arkansas-White Red region, Sabine-Neches (1201) and Nueces-Texas Coastal (1205) of the Texas-Gulf region, and Green-White-Yampa (1401) of the Upper Colorado region.

Indian and Federal Water Claims

Resolution of Indian and federal water claims could have significant impacts on western water use. Indian as well as federal claims on western water stem from vast land holdings and the judicially created Winters Doctrine that holds, among other things, that these lands have sufficient accompanying water rights to accomplish the purpose for which the lands were reserved.[1] A number of federal court decisions have supported the view that Indian water rights are created outside the system of state law and exist independently of it. Since virtually all western surface water has been put to use without regard for Indian rights, many existing users are threatened by resolution of Indian claims.

Indian and federal rights remain unquantified and, in spite of President Carter's "instruction to Federal agencies to work promptly and expeditiously to inventory and quantify Federal reserved and Indian water rights,"[2] these claims are likely to remain a source of great uncertainty for western water use for years to come. This issue is discussed further in section 4.

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[1] The 1908 Supreme Court decision in Winters v. United States held that Indian reservations had reserved water rights. Until 1955 the Winters Doctrine remained applicable only to Indian reservations. Since that time several Supreme Court decisions have extended the doctrine to any federal lands. See Heidi Topp Brooks, "Reserved Water Rights and Our National Forests," in Natural Resources Journal, vol. 19, April 1979, pp. 433-435.

[2] A June 6, 1978 message from Jimmy Carter to the Congress of the United States accompanying the President's water policy message.

AUGMENTING WATER SUPPLIES

Both the water supply and demand situations depicted above assume that there will be no major new sources of water. However, weather modifications, interbasin transfers, and icebergs are possible sources of increased supplies and water harvesting and desalinization may stretch the usable supplies in specific areas. Dams and reservoirs can increase water supplies available for specific purposes such as irrigation. Water impoundment, however, no longer is a means of significantly increasing the effective supply of western water; the limited supplies still remaining in the West's streams and rivers generally have value for fish, recreation, or preserving water quality. Thus, further construction of dams will divert water from one use to another but generally will not increase the overall supply. To the contrary, high evaporation rates from reservoirs in arid and semiarid lands reduce the effective water supply. Moreover, the best dam sites already have been exploited, and the costs of increasing irrigation water supplies through additional impoundment are high. For example, dams and reservoirs under consideration in California will cost $200 to $300 per acre-foot of water added to the effective water supply for irrigation, municipal, or industrial uses.[1] Improved farm management practices may increase the effective supply of water by enabling successful irrigation with saline or brackish water. This possibility is examined in chapter 6 on environmental impacts of irrigated agriculture.

Weather Modification

Research results have demonstrated that seeding of winter orographic clouds over mountainous areas can increase precipitation under some conditions.

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[1] Personal communication with Kenneth Turner, Manager, Agricultural Water Conservation Program, California Department of Water Resources, February 1980.

Generally only 20 to 50 percent of the water that is condensed in the formation of these clouds falls as precipitation; cloud seeding can increase snowfall in the mountains by as much as 20 percent.[1] More specifically, studies suggest that a coordinated program to seed the clouds of six mountain ranges in the Upper Colorado River Basin can increase snowfall sufficiently to provide an additional 1.4 to 2.3 million acre-feet of water a year at a cost of about $5 to $10 per acre-foot.[2]

The promise of increasing precipitation through winter cloud seeding was noted in a 1973 National Academy of Science panel report as follows: "in the longest randomized cloud seeding research project in the United States, involving cold orographic winter clouds, it has been demonstrated that precipitation can be increased by substantial amounts and on a determinate basis."[3] An optimistic appraisal of winter cloud seeding was confirmed in a 1978 report of the Weather Modification Advisory Board. The Advisory Board's recommendations were cautious, however, and stressed the need for additional experiments to be carried out in the Colorado mountains and new studies to be initiated in other mountainous climatic regimes such as the Sierra Nevada Mountains of California.[4] Despite the apparent consensus among scientists that the technology is available for significantly increasing precipitation from winter mountainous storms at low cost, no coordinated program has been established to take advantage of this technology.

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[1] U.S. Department of Commerce, National Weather Modification Policies and Programs: A Report to the President and the Congress (November 1979) pp. 12-14.

[2] Personal communication with Bernie Silverman, Chief, Atmospheric Water Resources Management, Water and Power Resources Service, Denver, Colorado, February 1980.

[3] Weather Modification Advisory Board, The Management of Weather Resources, Vol. 1 Proposals for a National Policy and Program. A report to the Secretary of Commerce, June 30, 1978, p. 50.

[4] Weather Modification Advisory Board, Management of Weather, pp. 52-53.

The largest potential increases in precipitation, at least in theory, lie in increasing the yield from cumulus clouds, which provide most of the precipitation in the world's principal food growing areas. An increase in our ability to control this rainfall, especially during the growing season, could be of enormous benefit to agriculture and perhaps reduce the need for irrigation. Unfortunately, increasing rainfall through summer cloud seeding has proven to be a much more difficult scientific problem than the seeding of winter orographic clouds. The complexity and variability over time and space of cumulus clouds have stymied or at least called into question the success of most efforts to increase summer rainfall. Nevertheless, there has been some encouraging evidence from seeding of summer cumulus clouds, and improved understanding of the workings of these clouds achieved in recent years should lead to better future results. In particular, scientists now have some understanding why past experiments sometimes produced negative results, and these should be curtailed in future tests. Overall, however, development of a reliable technology for increasing rainfall from summer cumulus clouds is some years off and must await both better understanding of the atmospheric processes involved and further experimentation.[1]

Even if a weather modification technology is established and the economics are favorable, there will be major institutional obstacles to adoption of an extensive cloud seeding program. Paying for the program, compensating the losers (whether real or imagined), allocating the additional water, and overcoming the fears that are sure to emerge among the people downwind from the cloud seeding are difficult problems that likely will stall efforts to increase precipitation until long after scientists and economists are comfortable with the technology. The task for winter seeding is particularly complicated since the losers (e.g., those with higher snow removal costs) are closer in both location and time to the seeding than are the beneficiaries (e.g., farmers perhaps hundreds of miles downstream who presumably receive more water many months later.) Analysis of several summer cumulus seeding projects suggests that the downwind effects are uncertain. Such uncertainties are bound to inhibit adoption of any major cloud seeding program.

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[1] Based on the conclusions of U.S. Department of Commerce, National Weather Modification, pp. 14-17 and Weather Modification Advisory Board, Management of Weather, pp. 53-57.

In spite of these obstacles, cloud seeding is used in a few western areas today, and its use is likely to spread as the value of water increases and the technology improves. Conservative estimates suggest that winter cloud seeding might add nearly 10 percent to the flow of the upper Colorado River, which may be a reasonable target for the turn of the century. Such an increase, however, would have little impact on the overall course of western irrigation. While a 10 percent increase would be significant within that area, it would be equivalent to only 0.3 percent of total western stream flows.

Water Importation

The scarcity of indigenous water resources in relation to demand has prompted a call for water imports from more amply endowed regions. Water importation has broad support within the Lower Colorado River Basin and the High Plains areas where current activities are dependent on nonrenewable water sources. But if the net water supplies within the West's water-scarce southern belt are to be increased, the water will have to be transported long distances. The Central Arizona Project currently under construction will make it possible to transport Colorado River water into the Phoenix-

Tucson area. However, this project will not increase effective water supplies within the water-scarce areas of the West. The water is already being fully utilized; the project largely will divert water to central Arizona that currently is going to southern California.

The Mississippi, Columbia, and upper Missouri rivers are the closest from which large quantities might be obtained. The availability of water for export likely would be contested vigorously in these areas. But even if there is plenty of water for export, several feasibility studies indicate that the costs of transporting it to the High Plains or Southwest would far exceed its value in agriculture. A study undertaken in the early 1970s of transporting water from the Mississippi River to the Texas and New Mexico High Plains showed only 27 cents in benefits for every $1 in costs. Even this ratio of benefits to costs probably overstates the attractiveness of the transfer since the study did not attribute any value to the water in the exporting basin and used energy costs which now appear much too low. For example, the energy costs alone at 1980 electricity prices in the area would exceed $400 per acre-foot of water delivered in the High Plains.[1] A more recent Corps of Engineers study of the feasibility of transporting water to various locations in the High Plains confirms the infeasibility of moving water long distances for agricultural uses. The Corps considered four potential import sources and routes for transferring from 1.0 to 7.2 million acre-feet per year. The estimated costs per acre-foot of water delivered to terminal storage points ranged from $352 to $880. For use in irrigation, there would be additional costs required to deliver the water to the farms.[1] In general the costs of transporting water from the Mississippi or Missouri rivers to the High Plains appear to be about an order of magnitude above the prices farmers in the High Plains currently can afford to pay for water and still irrigate profitably. Although economic feasibility has not been a necessary requirement for western water projects, the economics of such a water transfer project appear poor even by the standards of other water projects.

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[1] The Bureau of Reclamation study estimated that nearly 47 billion kWh of power would be required to deliver 5,794,000 acre-feet of water to the High Plains annually. At 5 cents per kilowatt hour, approximately the average 1980 cost of electricity in Texas, the cost per acre-foot is over $400. (See U.S. Department of Interior, Bureau of Reclamation, West Texas and Eastern New Mexico Import Project, Washington, D.C., 1973).

Icebergs

The availability of enormous quantities of freshwater trapped as polar ice has raised the possibility of diverting some of this water to the world's arid areas. A very optimistic assessment of the prospects for using Antarctic icebergs to supplement Southern California's water supplies came out of a 1973 study by the Rand Corporation.[2] This study concluded that delivering icebergs was both technically possible and economically attractive in comparison to some other proposals such as interbasin transfers and desalinization for supplementing water supplies. The scheme called for using nuclear tugs to tow iceberg trains attached by cables. Plastic films would supposedly reduce melting to about 10 percent per year. The operational costs of delivering a large iceberg train to California were estimated at $10 per acre-foot and the total costs of transport, conversion to water, and delivery to wholesale terminals in coastal areas were estimated at $30 per acre-foot.

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[1] The data on the Corps of Engineers study, which was done as part of a larger High Plains Development Study financed by the U.S. Department of Commerce and authorized by the Congress, is based on a report in The Cross Section, vol. 27, no. 3, published by the High Plains Underground Water Conservation District No. 1, March 1981.

[2] J. L. Hult and N. C. Ostrander, Antarctic Icebergs as a Global Fresh Water Resource, prepared for the National Science Foundation by the Rand Corporation, R-1255-NSF, October 1973.

More recent assessments of the technical problems and costs of delivering Anarctic icebergs to arid areas thousands of miles away have been less sanguine.[1] For example, preliminary studies of towing icebergs to Saudi Arabia were not encouraging. Geologists estimated an Artarctic iceberg would be completely melted as it passes through non-Arctic waters more than three weeks before it could reach Saudi Arabia.

The outstanding technical problems associated with the transfer and use of icebergs prevent any precise assessment as to the delivered cost of water from icebergs. But even if iceberg harvesting does show promise after allowing for technical, economic, and environmental considerations, it might be stalled by international political and legal issues concerning resource rights. Accordingly, there is little reason to expect that icebergs will be a promising source of water for the western United States, especially for irrigation purposes.

Water Harvesting

Harvesting rainfall by diverting the water to fields or into cisterns is an ancient technology which currently is used only sparingly in the West. Its primary uses are as a water source for domestic, livestock, or wildlife purposes, seldom for irrigation. Although some promising opportunities may have been missed by western farmers, water harvesting for irrigation will remain very limited in terms of both the areas having suitable topography and rainfall and the resulting increases to water supplies.

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[1] Jan van Schilfgaarde and Glenn J. Hoffman, "Future Sources of Water," an unpublished paper dated October 2, 1980.

Desalinization

The enthusiasm prevalent in the 1960s for using desalted sea water to make the deserts bloom was dampened by Clawson, Landsberg, and Alexander's conclusion that "the full and true costs of the proposed desalting projects, now and for the next twenty years, are at least one whole order of magnitude greater than the value of the water to agriculture."[1] Although research has brought technological improvements in desalting technology, rising energy costs have prevented significant improvements in the economics of desalinization. Three desalting processes are workable. A distillation process probably is best suited to desalting sea water, while either reverse osmosis or electrodialysis may be better suited to water with lower salt levels since the energy requirements of these latter techniques are directly proportional to the salinity of the water. Depending on the technology used and the initial and final salt levels, energy costs accounted for 12 to 54 percent of total desalting costs at 1974 price levels. But even when the process starts with brackish waters with salt levels well below those of sea water and ends with less than pure water, the most economical methods of desalting cost from $250 to $300 per acre-foot in the late 1970s.[2] These are plant site costs; additional costs would be required to deliver the water to farms.

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[1] Marion Clawson, Hans H. Landsberg, and Lyle T. Alexander, "Desalted Sea Water for Agriculture: Is It Economic?" Science, 6 June 1979, Vol. 164, pp. 1141-1148. Resources for the Future Reprint No. 78, July 1979.

[2] U.S. Bureau of Reclamation, California Department of Water Resources, and California State Water Resources Control Board, Agricultural Drainage and Salt Management in the San Joaquin Valley, June 1979, pp. 8-4 and 8-5.

In summary, although desalting is feasible under some circumstances for some uses of water, it is not now nor is it likely to become within this century an economical means of significantly increasing irrigation water supplies. The decision of the U.S. government to construct a desalting plant in Yuma, Arizona for the drainage waters of the Wellton-Mohawk Irrigation District was based on political rather than economic considerations. Desalinization is a very costly way of satisfying U.S. treaty obligations with Mexico regarding flows of the Colorado River. The plant, however, does enable the United States to avoid or at least postpone difficult political decisions required to implement an improved irrigation management scheme capable of accomplishing essentially the same goals at a much reduced economic cost.

Use of Low Quality Water Supplies

The preceding discussion of water supplies implicitly has been limited to supplies of fresh water meeting current standards of most agricultural as well as domestic and industrial users. However, there are large quantities of water available in the West that do not meet these criteria, and one means of increasing effective supplies might be to make use of lower quality water. In particular, large quantities of saline water are stored in some aquifers and lakes and all coastal areas have an essentially unlimited supply of sea water. Although (as noted above) the costs of desalinization exceed the value of water in most agricultural uses, there may be opportunities for using more saline water for irrigation.

Water qualities may be described in terms of the milligrams of total dissolved solids per litre (mg/l TDS). The higher the level of dissolved solids or salts (the term generally used to describe all these compounds) in the water, the lower the quality. All irrigation water contains some salts and concentrations of about 500 mg/l pose no problem to most irrigators.[1] Higher concentrations start imposing costs in the form of lower crop yields, higher water requirements to prevent salt buildup in the root zone, and increased management requirements to adapt to the high salt levels. (Section 6 examines the problems stemming from high salt levels as well as the extent of these problems in the West.) With careful management and good drainage, up to 1,500 mg/l TDS can be tolerated on all but the most salt sensitive crops with little loss of yield.[2] Furthermore, some crops can be irrigated successfully with water containing much higher salinity levels. Barley, a particularly salt-tolerant crop, is grown commercially in California with water containing several times these levels of salts. A field experiment has demonstrated that good cotton yields can be obtained with water containing 6,000 mg/l TDS and sugar beets is another crop tolerant of relatively high salt levels.[3] With scientists working to increase salt tolerance of a variety of crops, the options for irrigating successfully with saline waters are likely to expand in the coming decades.

A more extreme goal, but one being pursued optimistically by some researchers, is to develop a marketable crop that can be successfully grown with sea water, which has a salt level of about 35,000 mg/l. Various types of halophytes grown experimentally with sea water have produced yields of plant matter (suitable at least as an animal feed supplement) comparable to those on conventional farms.[1] Nevertheless, much research remains before sea water can be considered a suitable source of irrigation water.

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[1] U.S. Department of Interior, Bureau of Reclamation, Final Environmental Statement: Colorado River Water Quality Improvement Program, vol. I, May 1977, pp. I-11 to 21.

[2] Jan van Schilfgaarde and Glenn J. Hoffman, "Future Sources of Water," U.S. Salinity Laboratory, Riverside, California, unpublished paper, October 1980, pp. 10-11.

[3] U.S. Bureau of Reclamation, California Department of Water Resources, and California State Water Resources Control Board, Agricultural Drainage and Salt Management in the San Joaquin Valley - Final Report, June 1979, p. 3-1, and van Schilfgaarde and Hoffman, "Future Sources of Water," p. 11.

In summary, the technology currently exists to make more effective use of poor quality waters widely available in the West. Furthermore, research will increase the opportunities for using these waters in irrigation. On the other hand, there are important limitations to the feasible use of highly saline water. Success requires unusually high management skills and there is a risk of severely damaging the soils with the use of such water. In addition, since the value of saline water for use in irrigation always will be less than that of better quality water, the cost that can be justified to transport low quality water to a farmer's field necessarily will be less than for fresh water.

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[1] John Neary, "Pickleweed, Palmer's Grass, and Saltwort: Can we grow tomorrow's food with today's salt water?" in Science 81, vol. 2, no. 5, June 1981, pp. 39-43.

SECTION 4

WATER INSTITUTIONS

INTRODUCTION

Like labor, land, and seed, water can be viewed as another input into agricultural production. In one respect, however, it is radically different. Water is a "fugitive" resource. When it flows from one property to another, a characteristic of most surface and some groundwater supplies, it is difficult to establish a clear property right to it. Consequently, water is called a common property resource: it is accessible to many but owned by none until it is withdrawn for use. Water generally is not bought and sold in the marketplace as are other inputs. Instead, government, as guardian of public resources, allocates it by various legal and institutional means.

The federal government has not tried to establish a single legal or institutional regime to govern the country's freshwater supply. Instead, the basic task of regulating water use had been left largely to the states. The states have developed a myriad of institutions, laws and regulations to control their waters, reflecting in part both underlying variation in the supply, demand, needs, and other circumstances surrounding water use and different views of property rights and the role of the government. Furthermore, the demands placed on water institutions have changed over time, and the history of western water law records many endeavors by states to adapt and respond to new circumstances and problems.

When water was abundant relative to demand, the states played little role in its use. As the first farmers began to settle in the valleys close to streams, they diverted the natural flow of the stream to irrigate their fields. To give greater security to irrigators and to control conflicts between rival diverters, states developed the doctrine of prior appropriative water rights, the basic principle of which is "first in time, first in right." Once the readily accessible water was in use, expansion required dams, reservoirs, and canals to capture the heavy spring flows and carry it to undeveloped land farther away. The technical and financial demands of such projects, however, often exceeded the capabilities of private investors and even the states. These circumstances led to demands for federal assistance in constructing and financing western water projects. With these larger projects came both new opportunities for managing water resources and needs for institutions to realize their potential benefits. State laws led to the creation of irrigation districts, self-governing public corporations empowered to control water allocation within district boundaries. Likewise, advances in pump technology brought both new opportunities and institutional needs. As groundwater use increased beyond the capacity of the aquifers to recharge themselves, the states have sought ways to control withdrawals.

The rapid spread of irrigation throughout the West is at least partial evidence of the success of water laws and institutions in having met the demands placed on them. Today, however, water institutions face a new challenge. Western irrigators have increasingly come into competition for water with growing urban populations and expanding industries. As the demand for water, both for irrigation and other uses, has risen, the opportunities for developing additional supplies have decreased. With most prime sites for reservoirs already developed, the costs of construction high, and little unclaimed water left, additional surface water diversion has become costly and in many areas of limited potential for increasing usable water supplies. An alternative response to the problem of water scarcity is to increase the physical and economic efficiency of already-developed water resources. Proper incentives could encourage the adoption of conservation measures such as more efficient conveyance systems or less wasteful irrigation practices. A market-oriented allocation system would allow those with higher-valued uses to bid water away from the many lower-valued uses to which it is presently put. Such an approach, however, often requires modifications in present water laws and institutions. So far, the legal and institutional framework governing western water has been slow to respond to this latest challenge and remains a hindrance to the task of increasing the efficiency of water use.

This section examines existing water laws and institutions and assesses their impacts on the allocation of western water. The first part focuses on surface water and the second on groundwater.

SURFACE WATER INSTITUTIONS

Surface Water Law[1]

Riparian Doctrine--

The doctrine of riparian rights provided the legal basis for the earliest western water diversions. This doctrine, developed in England and employed in the relatively water-abundant eastern states, holds that an owner of land adjacent to a stream or pond has the right to make use of the water that flows by this property. The riparian water right is inseparable from the land. The holder of the right can make any "reasonable" use of this water so long as he uses it on the riparian land and does not cause a major inconvenience to other riparian users. At the same time, he is protected against the wasteful, unreasonable, or unbeneficial use of riparian waters by others. His use is correlative with other co-users, and there is no priority in right among users. Should drought cause a water shortage, all riparian users share in reducing their consumption.

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[1] Much of the discussion on water law is based on section 5 of George E. Radosevich, Western Water Laws and Irrigation Return Flow, a report prepared for and published by the U.S. Environmental Protection Agency, EPA-600/2-78-180, August 1978.

Once development looked beyond the lands adjacent to the streams or required modifications in the natural stream flow to enhance supplies, the riparian doctrine proved insufficient for the needs of the West. The need to encourage and safeguard private investments and to reclaim western lands necessitated a legal system providing greater flexibility in allocating water and more security in guaranteeing continued access to water sources.

Prior Appropriation Doctrine--

The doctrine of prior appropriation was developed in response to the shortcomings of the riparian doctrine for western development needs. Under the appropriation doctrine, a party diverting water from a stream and putting it to some beneficial use can make a claim to continued appropriation of similar amounts of water from that stream. As in a mining claim, the rule of "first in time, first in right" applies. The doctrine of prior appropriation has been adopted in all seventeen western states. The High Plains states of Texas, Oklahoma, Kansas, Nebraska, and North and South Dakota along with the three Pacific Coast states also have retained the doctrine of riparian rights in conjunction with that of prior appropriation. Only in California, however, does the riparian doctrine still have major significance. In all the other states which use a dualistic riparian/prior appropriation system of water law, new surface water claims can be made only under the prior appropriation doctrine.

In contrast to the riparian doctrine, water rights under prior appropriation are not tied to ownership of land or use of water on land bordering the stream. Instead, prior appropriation rights are acquired simply by diverting water from a stream, carrying it to the desired location and putting it to some beneficial use. At this point, the water right is created and the person can file for a permit (or license or decree depending on the state) that entitles him to continued use of the water so long as the use remains beneficial. The holder's right has priority over (or is senior to) all rights acquired after his, and is junior to all rights acquired before his. Should the stream flow fall below that needed to satisfy all appropriated rights, junior right holders would have to forego the exercise of their rights so as to allow senior holders to fully exercise theirs. The loss is not shared proportionally as it is under the riparian doctrine.

The acquired right is a real property right that can be sold, transferred, mortgaged or bequeathed. At the same time, it is a right only to use the resource, and states place varying restrictions on the use that can be made of the water. The right arises only at the point of diversion and is contingent on the beneficial use of the water. Should the holder be unable to make good use of the water, he has no right to divert it. Also, when the diverted water leaves the property of the holder, his right to it ceases and the water returns to the status of public property. Generally, rights also exist to these return flows, i.e., the return flow is often appropriated by some downstream user. Furthermore, the right pertains to a specific use and is fixed to a certain place of use (e.g., parcel of land in the case of irrigation). The amount of water as well as the time of year it can be diverted are generally specified.

Twelve western states also identify a ranked preference of use in their water law. Municipal and domestic uses are given top preference in all twelve states. In nine states, agricultural uses, including irrigation, get second preference. The preference rule allows preferred users to condemn the water of nonpreferred users in times of scarcity so as to satisfy the preferred need. Where preference rules exist, prior appropriation applies only within categories of users with similar preference ranking.

Besides condemnation, appropriative rights can be lost by abandonment, forfeiture, or adverse possession. If a holder fails to make use of a right for a specified period of time (usually 3, 5, or 10 years depending on the state), he is considered to have abandoned or forfeited his rights. Likewise, should another party make open and notorious use of someone else's water without the owner of the right taking any steps to remedy the situation within a period specified by law (usually five years), the holder may lose the right to the intruding party.

Types of Irrigation Organizations

In 1969, about 25 percent of the surface water used for irrigation was from on-farm sources.[1] By virtue of their location, these farmers independently divert water from streams and ponds for irrigation. Generally, they were the first to arrive in a region and retained senior rights to the natural summer flow of water. There is very little land or water left in the West for expansion of this type.

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[1] U.S. Bureau of the Census, Census of Agriculture, 1969, Vol. IV, Irrigation, U.S. Government Printing Office, Washington, D.C. 1972, p. 70.

The remaining 75 percent of the surface water is supplied by some type of irrigation organization. As land was irrigated farther away from the water source and reservoirs were built to increase the supply of water, irrigation organizations were developed to facilitate the delivery of water. The Census of Agriculture lists seven principal types of organizations which deliver water: unincorporated mutuals, incorporated mutuals, irrigation districts, Water and Power Resources Service (WPRS) constructed and operated projects, United States Bureau of Indian Affairs (USBIA) projects, state and local government projects, and commerical enterprises. The first three types account for 95.4 percent of all water organizations and 92.2 percent of all acreage irrigated by organization (see table 4-1).[1] From 1930 to 1970, the number of irrigation organizations decreased and their average size increased as many smaller organizations consolidated to provide better, more uniform service to their members.

Unincorporated mutuals are the simplest organizations, ranging from informal verbal agreements between two farmers to build a simple diversion on a mutually held stream to several farmers who build and maintain a canal for common use. The average unincorporated mutual supplies water to

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[1] The appendix (pp. 9-10) discusses some of the problems of the irrigation censuses as a source of irrigated acreage data. However, there is no reason to expect these data result in major distortions in the relative allocation of irrigated acreage among irrigation organizations and there are no alternative sources of such data.

Table 4-1. The Size and Number of Various Types of Irrigation Organizations in the West in 1969

Organization	Percent of U.S. Total for All Types: Number of Organizations	Percent of U.S. Total for All Types: Acreage Irrigated by Organization
Unincorporated Mutual	53.7	10.8
Incorporated Mutuals	32.6	34.3
All Districts (Irrigation & Other)	9.1	47.1
Water and Power Resources Service Constructed and Operated*	.7	1.8
U.S. Bureau of Indian Affairs	.7	2.9
State and Local Governments	.5	.2
Commercial Companies	2.7	2.9
	100.0	100.0

Source: U.S. Bureau of the Census, Census of Agriculture, 1969, Volume IV, p. XXV.

*Most WPRS projects are turned over to some other type of irrigation organization once construction is completed. Acreage serviced by WPRS constructed and user operated projects accounted for nearly 27 percent of the acreage irrigated by other organizations.

seven or eight farms. While accounting for over half the number of irrigation organizations, unincorporated mutuals supply water to only 11 percent of the land irrigated by all organizations.

The incorporated mutual is simply a larger, more formal version of the unincorporated model. The users own shares in the organizations and supply water to themselves at cost. An appointed board of directors oversees the operation. This type of organization accounts for about one-third of the organizations in number and a little more than one-third of the acreage.

Irrigation districts are organized by law as self-governing and self-financing public corporations with the powers of taxation and eminent domain. The government designates certain acreages of land which are accorded water rights. All landowners are assigned one vote regardless of acreage. While they account for only 10 percent of water organizations, they serve almost half of all land irrigated through organizations.[1]

Financial Factors Shaping the Water Industry

Over the years two factors have had a major impact on the allocation and low cost of surface water. First, most organizations are more accurately "users' cooperatives" functioning primarily to benefit farmers; commerical firms play a small part in this water industry. Second, government has played a significant role in underwriting the cost of providing water to these organizations.[2]

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[1] U.S. Bureau of the Census, Census of Agriculture 1969, vol. IV, p. XXVII.

[2] Much of this discussion is based on the excellent study by Richard E. Caves, and Julius Margolis, Northern California's Water Industry (Baltimore, Johns Hopkins University Press for Resources for the Future, 1966).

Typically, irrigation organizations operate as "users' cooperatives," providing water at cost to members. Generally, the user is charged only a nominal transaction cost for the water. The organizations compete among themselves for more dependable and cheaper water supplies instead of for new customers. This cooperative approach to providing water undercuts the opportunities for commercial firms entering the industry.

The cost structure of the industry further limits the role of commercial firms. Fixed costs, which include dams, wells, canals, ditches, and pumps, are a large portion of the total costs of delivering water. In view of the substantial economies of scale associated with constructing such facilities, the costs of delivering water tend to fall as the size of the water project increases. Public agencies generally are better positioned to capture these economies.

A significant portion of water industry expenses is financed not by operating revenues paid by the water user but by public taxes. This is true of both federal (WPRS) projects and irrigation district operations. Among the powers vested by states in irrigation districts is the power to tax nonwater users within their boundaries. For [illegible] the Fresno Irrigation District in the Central Valley of California received assessments from landowners in the district totaling $2,162,991 in 1977. Approximately $450,000 or 22 percent was obtained from nonwater users, like the city of Fresno.[1]

The evolution and magnitude of subsidies associated with federal irrigation projects was discussed in section 3. That discussion indicates how a series of amendments to the 1902 Reclamation Act and the administrative decisions of WPRS and its predecessor agencies have provided federal water to irrigators at very favorable terms. Indeed, when operating and maintenance costs are accounted for, farmers have paid only about 3 percent of the construction costs of federal irrigation projects. Inflation combined with the long-term fixed rates charged irrigators have resulted in water charges which even fall below operating and maintenance costs on some projects.

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[1] Conversation between James Hanson and Howard Keck, Fresno Irrigation District, July 19, 1979.

Since only some farmers benefit from these subsidies, federal policy has produced some striking contrasts among the water costs of neighboring irrigators. In Kern County, California, for example, recipients of WPRS water paid $3.50 per acre-foot for water in the mid-1970s while their neighbors receiving water from the California Department of Water Resources paid $22.42 per acre-foot.[1] Beneficiaries of federal water in the county receive an explicit subsidy through interest exemption and the allocation of hydroelectric power revenues to cover part of the construction costs. Inflation and the use of 40-year repayment contracts with fixed water prices provide a sizable additional subsidy. Indeed, the differences between the prices paid by those fortunate enough to receive federal water and most all other users are likely to widen considerably over the next decade. While most of the long-term federal contracts will not expire until the 1990s, Kern County water costs on state projects are expected to rise to about $70/acre-foot (in 1980 prices) within about five years due largely to higher energy costs.[1]

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[1] U.S. Department of Interior, Office of Audit and Investigation, Review of the Central Valley Project, Bureau of Reclamation, January 1978, p. 44.

Government largess on such a grand scale has important implications for the wealth and competitiveness of different farmers. The 1902 Reclamation Act supposedly limited an individual to 160 acres and a farm couple to 320 acres of land receiving federal water. The intent to provide water solely for small family farms has been violated in practice through lax enforcement of the law and loose administrative practices which permit unlimited leasing and multiple ownership arrangements. While the great majority of farm operations comply with a 160- or 320-acre limitation, much of the irrigable land is operated in larger units. Of the 126,000 owners of 8.8 million irrigated acres supposedly subject to acreage limitations, nearly 91 percent own 160 acres or less and 98 percent own 320 acres or less. The remaining 2 percent, however, own 27 percent of the land. The 340 largest owners (comprising less than one-third of 1 percent of the farmers receiving water from federal projects) own 11 percent of the land receiving subsidized water.[2]

Clearly there are important equity issues involved in the distribution of federal water subsidies. But these are not of direct conern to this study. The distribution of the subsidies, however, is important for this study to the extent that it affects the efficiency of water use and, thereby, total production from irrigated farms. Central to this issue is the extent to which there are economies or diseconomies of scale on irrigated farms.

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[1] Based on a comment by Gerald Meral, Deputy Director, Department of Water Resources, State of California, at a June 1980 water workshop held at the Ford Foundation in New York City.

[2] U.S. Department of Agriculture, Farmline, vol. 1, no. 6, September 1980, p. 4.

Proponents of eliminating the acreage limitation emphasize that there are significant economies of size to be gained by allowing the large farmer to exist. They argue that lower food prices from these large farms benefit the consumer and discourage inflation. On the other side, limitation proponents suggest that the 160-acre limitation is necessary to distribute the subsidy among a greater number of people and to preserve the values of the small farm. Furthermore, they point to evidence suggesting that relaxation of the acreage limitation will not significantly decrease the costs of food production and aid the consumer.

Research on economies of scale of irrigated farms has been limited and inconclusive as to the implications of enforcing the 160-acre limit or some variation of it. Research published in the early 1960s indicated economies of scale existed for farms up to 600 to 1,000 acres.[1] More recently, the notion that limiting a farm to 160 or 320 acres would involve considerable economic inefficiency has been challenged by David Seckler and Robert Young, who suggest there may be no significant economies of scale on irrigated farms exceeding 180 acres.[2] A U.S. Department of Agriculture study of the effects of imposing the 160-acre limitation on farms in Nebraska, Wyoming, California, and Washington concluded that large farms in all regions did have lower production costs per unit of output than small farms. However, 98 percent of the cost advantages achieved by larger operations were captured by farms which averaged between 320 and 640 acres.[1]

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[1] See the discussion in William E. Martin, "Economies of Size and the 160-Acre Limitation: Fact and Fancy," American Journal of Agricultural Economics, vol. 60, no. 5, December 1978, Proceedings Issue, p. 925.

[2] David Seckler and Robert A. Young, "Economic and Policy Implications of the 160-acre Limitation in Federal Reclamation Law," American Journal of Agricultural Economics, vol. 60, no. 4, November 1978, pp. 576-588.

Although the question of economies of scale on irrigated farms remains open, it does not appear that resolution of the acreage limitation issue will have significant impacts on farm output grown with federally supplied water. This is especially true since Congress is moving towards increasing the acreage limitation. Illustrations of support for relaxing acreage restrictions include a bill to raise the limit to 1,280 acres including owned and leased land which passed the Senate in 1979, and another bill to increase the limit to 960 acres with allowance for leasing up to 2,400 additional acres which was recommended by the House Committee on Interior and Insular Affairs in June 1980.[2]

One result of the debate over the appropriateness of federal financing of western water projects and enforcement of the 160-acre limitation is that the WPRS is being forced to reexamine the policies providing such large subsidies to irrigators. As indicated in section 3, a major source of subsidization results from fixing the water rates for forty-year periods. The Service has responded to this problem by separating the operational and maintenance (O&M) costs from the repayment costs in its new contracts. O&M costs now are renegotiated every five years to make allowances for inflation while only the repayment costs remain fixed. These contract changes are not retroactive, however, and will only affect new contracts or old contracts as they expire. In California, over 80 percent of the water delivered under current contracts will not be renegotiated until the 1992-1996 period, suggesting a considerable lag before there is much effect from this policy change.

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[1] U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, The U.S. Department of the Interior's Proposed Rules for Enforcement of the Reclamation Act of 1902: An Economic Impact Analysis, ESCS-04, Washington, D.C., 1980, 61 pp.

[2] U.S. Department of Agriculture, Farmline, vol. 1, no. 6, September 1980, p. 4.

Federal Versus State Control of Water Resources

Another area of some controversy involves the role of federal and state governments in controlling western water. Through a series of acts in 1866, 1870, and 1977, the federal government granted each state power to distribute its water. The federal government reserved water for use on federal lands and according to the Constitution retained power to intervene in water use if it affected navigation.[1] While federal construction of large irrigation projects brought further federal involvement, section 8 of the 1902 Reclamation Act provided that federal projects must conform to state water laws and that nothing in the Act could be interpreted as altering state water laws.[2]

Nevertheless, determining the appropriate role of the federal government in western water development and use remains controversial. The issues initially centered around the unspecified water claims for federal lands and the huge subsidies for water projects. More recently western water has loomed increasingly important for achieving national objectives such as development of the West's enormous energy resources or use of some of the relatively undeveloped areas for housing new weapons systems. Critics of past policy argue for either greater federal influence over the use or distribution of the water or reduced federal support of water projects. The western states, on the other hand, are extremely sensitive to any efforts to reduce their sovereignty over water and reluctant to forego federal financing of water projects. They argue that the federal money is well spent and generates benefits which accrue to the nation as well as the West. They also note that the western method of water appropriation works well, having been developed over time, and any involvement by the federal government would confuse and frustrate the present system.

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[1] Radosevich, Western Water Laws, p. 38.

[2] U.S. Department of Interior, U.S. Department of Agriculture, and Environmental Protection Agency, Irrigation Water Use and Management: An Interagency Task Force Report (June 1979), p. 49.

It was in this climate that President Carter undertook to develop a national water policy. As a presidential candidate in 1976, Carter made it clear that he regarded many water projects as environmentally destructive boondoggles, and that, if elected, he was going to bring about reform. Yet, it came as a big surprise to most people when, scarcely a month into his presidency and in the midst of a severe drought in much of the West, Carter sent Congress a revised FY78 budget deleting $268 million for eighteen major water projects, with a total price tag in excess of $5 billion.

Other aspects of Carter's water policy were outlined in his June 6, 1978, message to Congress and subsequent releases. Guy Martin, Assistant Secretary for Land and Water Resources in the Department of the Interior, listed the primary concerns as: (1) restructuring the Water Resources Council (WRC); (2) fundamentally changing the 1902 Reclamation Act to better suit today's situation; (3) redefining the methodologies of justifying and financing water projects; (4) placing increased emphasis on water conservation; and (5) assessing new demands for water and the ability of present systems to meet these demands.[1] In January, 1979, President Carter issued an executive order for the WRC to conduct an independent financial review of the water projects before Congress.

Carter's initiative proved to be both poorly timed and politically naive. The "hit list" was reported in the Denver papers the same day the western governors and the recently appointed Secretary of the Interior Andrus convened a conference to discuss the problems of the drought. Although some groups in the West welcomed the President's initiative as necessary for improved management of their water, the area's political leadership was strongly opposed and saw Carter's efforts as an infringement on western water rights. This view was summarized by Utah's governor, Scott Matheson, chairman of the National Governors' Association Subcommittee on Water Management, as follows:

> The options that the administration wants to pursue in the name of conservation not only could preempt the states in their traditional role in conserving water but would also emasculate the state's prerogatives in allocating water resources.[2]

Many of the Carter administration's water reform efforts have been stymied by the Congress. Strong bipartisan support emerged for the long-standing congressional practice of log rolling, of putting good, bad, and mediocre projects into one big bill and resolutely fending off efforts to pare it back. Congressional response included restoring water project funds to the FY 1978 budget, prohibiting the Water Resources Council from spending any funds for independent project reviews, and, in legislation that passed the House of Representatives in 1980, eliminating all funding for the Council. Although the funds were authorized in 1980 to keep the Water Resources Council going, the Council has not been able to play the strong role in implementing a national water policy that the Carter administration hoped it would.

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[1] Guy R. Martin, "The National Perspective" in Western Water Resources, Coming Problems and the Policy Alternatives, Federal Reserve Bank of Kansas City Symposium, Boulder, Colorado, September 27-28, 1979, pp. 185-198.

[2] Scott M. Matheson, "A Western Governor Looks at Water Policy," in Western Water Resources, Coming Problems and the Policy Alternatives, Federal Reserve Bank of Kansas City Symposium, Boulder, Colorado, September 27-28, 1979, pp. 104-105.

Despite these setbacks, the efforts of the Carter administration were not without impact. A number of projects were terminated, there was a definite curtailment in Congressional support for irrigation projects, and future WPRS projects are likely to focus much more on hydropower development and providing water for municipal and industrial use.[1] Nevertheless, federal support of new irrigation will continue. As of 1980, Congress had authorized and funded 1.3 million additional acres of full service irrigation which probably will be completed. The Columbia Basin Project with 500,000 acres is the primary project in this group. Furthermore 2.5 million acres of supplemental service probably will be added, including 1 million acres under the Central Arizona Project. Congress authorized but did not fund an additional 150,000 acres of full service and 150,000 acres of supplemental service which have a good chance for being constructed.

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[1] Based on James Hanson's conversation with John Anderson, Bureau of Reclamation, Washington, D.C., March 31, 1980.

On the other hand, there are numerous projects which, though authorized by Congress, have not been funded and appear to be legislatively dead.

The Reagan administration clearly is more sympathetic to the states' views on issues involving water planning and control than was the Carter administration. But the impact of the new administration on federal support for water projects is uncertain. In a February 1981 meeting with eleven western governors, Interior Secretary James Watt reportedly asked the governors to come up with creative financing structures that would provide the states with more of a role in planning the massive water development projects they desire. He further promised to seek an end to current policy of returning unappropriated water rights to the federal government. The message received by at least one governor, John Evans of Idaho, was that the Reagan administration would be receptive to water projects.[1] Nevertheless, significant increases in federal funding for western water projects would be inconsistent with the administration's commitment to cut federal spending. Some reduction in federal funding of western water projects seems certain to result from Reagan's efforts to cut the budget. And if block grants to the states replaced federal funding that previously was tied to projects (a funding approach more consistent with the philosophy of the Reagan administration), many states may find more productive outlets for the funds than the water projects they currently support. On balance a major expansion of federal funding for western water projects seems unlikely under the current administration.

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[1] Joanne Omang, "Western Governors Announce Accord with Secretary Watt," Washington Post, February 26, 1981, p. A5.

Indian Water Rights

Another major issue that could affect the control and use of western water is the dispute over Indian water rights. Claims by Indians to a larger share of western water resources could change the availability and perhaps the price of irrigation water in many parts of the West. Historically, little consideration was given to the potential needs of Indians when the federal and state governments allocated western water resources. Indians are a minor consumer of water; the Bureau of Indian Affairs (BIA) projects account for only 2.9 percent of the acreage irrigated with water from irrigation organizations. Recently, however, several Indian tribes have made major claims to already-appropriated surface and groundwater resources, contending that they have rights senior to those made under state law. The Navajos may lay claim to as much as a third of the flow of the Colorado River. In New Mexico, claims by several tribes to waters of the Upper Colorado Basin are many times the entitlement of the entire state to the water of the region. Even the water supply for the city of Los Angeles is endangered by Indian claims. Indeed, the problem of Indian claims has been termed "ubiquitous" since almost anywhere there is an Indian reservation, there is potential for dispute. This has not only threatened existing reclamation and irrigation works but also cast uncertainty over the future development of water resources in the West.

The source of the conflict rests in the nineteenth century federal acts that gave states jurisdiction over all non-navigable water in the public domain. When the federal government withdrew land from the public domain for some purpose (e.g., to create an Indian reservation), there existed no provision for allotting it water rights. However, in 1908 the Supreme Court in Winters vs. United States found that when the federal government withdrew lands for any purpose, it at the same time implicitly withdrew sufficient unappropriated waters from the public domain to accomplish this purpose. In the Winters case the court ruled that when the federal government created the Belknap Indian Reservation in Montana, it also appropriated sufficient water from the unappropriated flow of the Milk River to meet the needs of the reservation. The Winters doctrine allows claims to be made to any water unappropriated at the time that the land was withdrawn with priority dating back to this time. Although the priority of Indian claims has not been clearly established by either the courts or executive branch, the Winters doctrine appears to give them seniority dating from the late nineteenth and early twentieth centuries when their reservations were created.

There also has been no determination as to the quantity of water associated with Indian rights. Some claim that the quantity of water is limited to the amount needed to meet the original purpose of the land. Reservations were originally envisaged as agricultural communities and thus have rights to water commensurate with needs of irrigation, stock, and domestic use. However, Indians claim that since reservations are now regarded as the permanent homelands of their tribes, any use of water that contributes to the development of these homelands must be satisfied under the Winters doctrine--be it for agriculture, mining, industry, etc. The Supreme Court has ruled in one case that reservations are entitled to water sufficient to irrigate all reservation lands that can be irrigated "practically"--regardless of what the water is actually used for.[1] This decision leaves another question unanswered: if a reservation is unable to put to use its entire allotment of water, can it still lay claim to the water and lease or sell it? If so, irrigators using contested water might not actually lose their water but instead would pay royalties to the reservation for its use.

In 1977, the Carter administration stated its intention to resolve quickly all uncertainty about the quantity of water claimed for federal enclaves--including military reservations, federal lands under the Park Service, Forest Service and Bureau of Land Management, and Indian reservations. Later, Indian claims were exempted from these discussions. At present, federal policy on resolving Indian claims is simply to allow settlements on a case-by-case basis through negotiating among the concerned parties or, if that fails, by litigation. As of May 1980, there were forty-seven cases in litigation dealing with Indian water rights in ten states. This process promises to be long and drawn out with, at present, little indication of how the courts will rule. In the meantime, there will be added risk to investments dependent on water resource development in areas where the rights are in dispute.

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[1] Arizona v. California, see Richard Sims, "Issues in Determining Indian Water Rights," in Western Water Resources: Coming Problems and the Policy Alternatives, a sumposium sponsored by the Federal Research Bank of Kansas City, September 27-28, 1979, p. 71.

Institutional Obstacles to Water Use Efficiency

Future development in the West (for reasons examined in section 3) will depend increasingly on using supplies more efficiently and allocating them to higher value uses. Current and expected future conditions are very different from those that prevailed when most of the laws were written, the water rights were acquired, and the water distribution organizations were established. Consequently, it is not too surprising that there are important institutional obstacles to achieving greater efficiency in the use of western water.

Efficiency in the allocation and use of scarce water resources depends on the facility with which the resources can be transferred from one use to another in response to changing conditions and on the degree to which transfer decisions reflect social benefits and costs. Unrestricted free-market transfers are seldom permitted and, indeed, often would not result in socially efficient uses of water in view of the importance of third party effects. Third parties are those who are not directly a part of the transaction (i.e., as buyer or seller) but are affected by the transfer. Such effects are common and often important in surface water transfers, especially since transfers tend to alter the availability of drainage waters.

Irrigation as the largest water user, holder of most of the preferred water rights, and a relatively low-value user, is central to achieving efficient water use; the incentives provided farmers to use water more efficiently and their ability to transfer water to other uses will affect both the future role of western irrigation and the overall development of the region's resources. The following discussion examines some features of western water law that pose obstacles to achieving a more efficient use of the surface water currently used for irrigation. This is followed by a brief look at an irrigation district that has developed effective water markets and at one type of water institution that offers some promise for promoting major improvements in water allocations but would require adjustments in the water laws of most western states.

Irrigation water rights are "appurtenant" to only the land specified in the permit which grants the right. That is, the right attaches to specific lands and cannot be changed without approval of the state agency issuing the permit. In many states water rights originally were attached to the land to help prevent fraudulent land and water sales practices common to early settlement schemes. To the extent that these provisions still impair transfer of water among alternative lands and uses, they may prevent efficient water use. Generally water rights can be transferred to other land so long as the rights of third parties are not impaired. However, the appurtenancy rule is stricter in some states. For example, a few states will approve transfers only for uses other than irrigation or if continued irrigation of land to which the right is presently appurtenant is no longer beneficially or economically practical.[1]

Some states limit the diversion of surface water our of its basin of origin. Four states--Colorado, Nebraska, Texas, and Oklahoma--restrict water exports to levels that will not impair present or prospective users. In the case of Texas, no water can be exported if in the next fifty years it seems likely that it will be reasonably used within the basin.

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[1] Radosevich, Western Water Laws, p. 63.

"Beneficial use" provisions of western water laws are intended to prevent the wasteful use of surface water resources. These provisions generally stipulate that both the purpose to which the water is put, as well as the manner by which it is applied, must be beneficial. California law requires that water allocated under appropriative rights be limited to that reasonably required for beneficial use. Likewise, other states specify that water allocated for irrigation should not surpass the amount required by good agricultural practices or by reasonably intelligent and diligent use. Some states go further and impose additional criteria for establishing the amount of water to be allocated to an applicant--termed the statutory duty of water. These include quantified limits. Idaho, Wyoming, and North Dakota permit 1 cubic-foot per second (cfs) of water per 50, 70, and 80 acres, respectively. South Dakota and Nebraska allow 1 cfs per 70 acres but no more than 3 acre-feet per acre. Montana and Kansas also have quantified limits.

Beneficial use provisions are frequently vague and always difficult to enforce. Courts often have resorted to using the custom of the local community as the standard of what is beneficial and reasonable though the community's customary use may not be particularly efficient. So long as the farming methods used are deemed reasonable for that community, the farmer need not "use methods which are costly in labor and money simply because some waste can be saved thereby."[1]

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[1] Twin Falls Land and Water Co. v. Twin Falls Canal Co., District Court of Idaho, 1933. Cited in George Radosevich, Western Water Laws, p. 61.

Despite their intent to prevent wasteful water use, the beneficial use provisions tend to inhibit water transfers and incentives to conserve. For example, an irrigator may be unwilling to temporarily transfer his water right to another party because he fears the transfer will be construed as evidence that he no longer can put the water to beneficial use--in which case he loses his right. The courts generally have not interpreted transfers in this manner but this fear still inhibits the exchange of water and is the basis of the "use it or lose it" philosophy influencing the use of much of the West's water.

Moreover, adopting more efficient methods does not guarantee that a user will have more water either to sell or use himself. To the contrary, a strict interpretation of the "beneficial use" doctrine suggests that water saved from evaporation or seepage losses by some act of improvement does not automatically accrue to the person making the improvement. In the case of on-farm improvements, greater efficiency in water use can mean a loss of part of one's water rights. If a farmer improves his conveyance system, distribution system or scheduling of irrigation applications, the water saved could not be used on other lands according to the appurtenancy rule. Instead, since less water would not be needed to accomplish the intended beneficial use, the water saved could be declared in surplus of the amount needed and forfeited. Consequently, farmers may overirrigate or otherwise waste water which they are allotted rather than risk losing it through nonuse.

Similarly, persons are discouraged from "salvaging" water in other ways because of the uncertainty of who will have priority for its use.

Some innovative parties have tried to establish rights to water salvaged by lining canals or destroying water-absorbing plants that border canals. Courts, in some cases, have refused to grant these parties rights to the salvaged water senior to those who had prior rights to flow. In these cases, the party that had made the improvement could lose its allotment in times of shortage while the senior right holders reap the benefits of the conservation efforts. A more common judicial interpretation has been to grant the party that has made the improvement priority in right to the salvaged water. However, there is some doubt that this interpretation will hold in future contests when water is scarcer and there is greater demand for nonagricultural water uses.

Improving efficiency of water use is further complicated when the water lost by the initial appropriator makes its way back to the original stream or into a groundwater aquifer where it is appropriated by others. In some states, such as Arizona, courts have ruled that while downstream users can appropriate return flow water, they cannot prevent upstream users from adopting more efficient means that prevent this return flow. Other states have taken the opposite position, ruling that upstream irrigators cannot change their methods if the improvement will detrimentally affect downstream users who rely on runoff and seepage for their supply of water.

The rights of third parties comprise another impediment to water transfers. In general, transfers of appropriative rights are prohibited if they somehow impair third party rights. Often water transfers would affect return flows and groundwater recharge on which other farmers depend.

There has been no easy method of resolving these problems and the costs of litigation often exceed benefits accrued by the transfer.

There are scattered areas in the West where at least limited water markets have developed. Most notable among these is the Northern Colorado Water Conservancy District (NCWCD). This District, which was established in 1937 to manage and distribute water from the WPRS's Colorado-Big Thompson project, has developed rental and water transfer markets.[1] Permanent transfers of water rights are permitted by the District as long as the new use is considered beneficial and is within the confines of the District. Temporary or seasonal transfers of water also are permitted, adding an important degree of flexibility for moving water to high-value uses in response to unforeseen events. The price of the water is arranged between the buyer and seller, and is not of concern to the District. The price of water traded within the District has risen from about $30 per acre-foot in 1962 to $1,200 in 1978.[2]

Three reasons have been cited for the success of water markets in this area of Colorado.[3] First, the irrigation company owns the water rights. Consequently, the rights are associated with shares in the company and are not attached to the land. The shares are personal property and can be transferred freely, thus avoiding the forfeiture problem associated with the appropriation doctrine. This feature also enables the District to get around the prohibition against farmers selling water supplied from federal projects. Second, privately owned storage reservoirs provide needed flexibility in the system to accommodate seasonal and permanent transfers. And third, there are no legal problems associated with the transfer since the water comes from a transmountain transfer and, therefore, is supplemental to the natural flow of the local Big Thompson River. Unfortunately, the factors which have contributed to the improved efficiency of water use in the NCWCD suggest it has limited applicability as a model for other areas.

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[1] A much more detailed discussion of the Northern Colorado Water Conservancy District is available in L. M. Hartman and Don Seastone, Water Transfers: Economic Efficiency and Alternative Institutions, Baltimore, Johns Hopkins University Press for Resources for the Future, 1970, chap. V, pp. 45-60.

[2] Raymond L. Anderson, "Transfer Mechanisms Used to Acquire Water for Growing Municipalities in Colorado," a paper prepared for the session Economic Issues in the Transfer of Water Rights at the Western Farm Economics Association meeting, July 24, 1978, p. 6. Anderson suggests the effective prices may have been somewhat higher since the system does not deliver a full acre-foot per unit in most years.

[3] Raymond L. Anderson, "The Irrigation Water Rental Market: A Case Study," Agricultural Economics Research, U.S. Department of Agriculture, June 1961, pp. 54-58.

Water banking has been proposed as a more generally applicable scheme for facilitating water transfers. A plan proposed for California would establish the local state agency in each district as the water bank.[1] Water banking would be classified as a "beneficial use" to avoid forfeiture under the appropriation doctrine. The banks would not collect the water in a physical sense but merely arrange transfers. The purchase price would rise or fall depending on the interaction of supply and demand. This particular proposal authorizes the bank to add a small charge to the price to cover any transfer costs and also to reimburse third parties for damages. Participation would be voluntary and the only required change in the water law would be to clasify water banking as a beneficial use. Such a system should encourage owners of water rights to conserve water and use it on one's own land only to the point where its marginal value in use equals or exceeds the selling price. Water banking would provide a method of transferring water from lower-valued to higher-valued uses and, thereby, help readjust the historical misallocation created by water rights allotted on a "first come" basis at a time when water was not viewed as a scarce resource.

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[1] Sotirios Angelides and Eugene Bardach, Water Banking: How to Stop Wasting Agricultural Water? Institute for Contemporary Studies, San Francisco, California, 1978, 52 pp.

GROUNDWATER INSTITUTIONS

Groundwater Law[1]

The introduction of groundwater pumping initially did not lead to situations of obvious conflict requiring legal or institutional intervention. Thus, the earliest legal doctrine governing groundwater use was that of absolute ownership. Farmers' decisions based on the profitability of pumping water comprise virtually the sole determinant of use under this doctrine.

Uncontrolled groundwater use, however, has resulted in a variety of problems. Where pumping exceeds recharge, pumping lifts rise, well yields decline, seawater may intrude into and contaminate an aquifer, or neighboring lands may subside causing damage which is especially serious in urban areas. Furthermore, since many aquifers are interconnected to streams and rivers, groundwater pumping may jeopardize the rights of surface water users. The emergence of these problems along with improved knowledge of aquifers have brought an increased appreciation of the need for better groundwater management. Although groundwater law has developed more slowly than surface water law, a variety of legal approaches to groundwater control have emerged and further changes are being debated in the legislatures of many western states.

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[1] The following discussion of groundwater law draws on several sources, especially Radosevich, Western Water Laws, pp. 42-43 and 55-58; Governor's Commission to Review California Water Rights Law, Final Report, Sacramento, December 1978, pp. 140-143; and The John Muir Institute, Inc., Institutional Constraints on Alternative Water for Energy: A Guidebook for Regional Assessments, prepared for the U.S. Department of Energy, November 1980, pp. 27-30.

Texas is the sole western state to retain the doctrine of absolute ownership. Under Texas law and the judicial interpretations of the state courts, essentially all groundwater is considered to be the private property of the person with title to the land above it. The water can be withdrawn for use or sale without any effective control by the state. Furthermore, the landowner is not liable for damages such as land subsidence and falling water tables that his pumping might inflict on neighbors.

Even though the state of Texas does not regulate the landowner's use of groundwater, owners overlying a defined groundwater reservoir voluntarily may adopt well regulation through mutual association in an underground water conservation district. A number of these conservation districts have been formed, several within the High Plains.

The vast majority of western states employ the concept of prior appropriation to groundwater as well as surface water. While there is a great deal of variety as to the level of state control imposed under this system, all follow the basic principle that a person can be granted a permit or license to pump water if it does not adversely affect prior groundwater appropriations and is used in a beneficial manner in conformance with other regulations. In practice, however, this doctrine seldom has been applied to prevent depletion of an aquifer and the resulting adverse impacts mining imposes on all users of the aquifer. Laws on preference of use, priority, appurtenance, forfeiture, and abandonment apply similarly to groundwater as they do to surface water.

Nebraska employs a reasonable use doctrine for control of groundwater use. This doctrine holds that landowners overlying an aquifer have co-equal rights to the water and are limited to reasonable use. Lacking any comprehensive groundwater law, application of the reasonable use doctrine recognizes the interdependence among neighboring pumpers and attempts to modify the complete disregard the absolute ownership doctrine has for the negative impacts one farmer's pumping may impose on others. This doctrine does, however, create uncertainty as to what comprises reasonable use. Limitations of the reasonable use doctrine for controlling groundwater supplies have led Nebraska to place increasing reliance on Natural Resource Districts to limit pumping. In the absence of a comprehensive groundwater law, the restrictions imposed by these districts are sure to be challenged with increasing frequency in the courts. Until passage of its Comprehensive Groundwater Act in 1980, Arizona also employed the reasonable use doctrine. However, in part as a condition for participating in the Central Arizona project, Arizona's new groundwater act adopts the prior appropriation doctrine and pumpers will be required to have permits.

California has adopted a refined version of the reasonable use doctrine termed correlative rights. This doctrine holds that every overlying landowner may make reasonable use of his groundwater as long as the water is plentiful. When supplies are threatened by overuse, each owner receives a share of the resource in proportion to his percentage of the overlying lands. All overlying uses are correlative with each other regardless of when they were initiated; there is no priority accorded early users. Transfers to another basin are permitted only where the water supply exceeds the needs of overlying properties.

Groundwater Management Organizations

Most western states have organizations with groundwater management functions ranging from administering well permits, policing water use, approving transfers, adjudicating water rights, and controlling water quality. At the state level these organizations include departments of water resources, offices of state engineers, and water commissions and boards.

In addition, many states permit the formation of special districts at the local level to regulate or manage groundwater. Locally controlled groundwater management districts are now common in areas with critical groundwater problems in California, Texas, Nebraska, Kansas, and Colorado. The example of the Texas groundwater conservation districts was mentioned above. The first and largest of these districts was established in 1951 when residents in a thirteen county area voted to form the High Plains Underground Water Conservation District No. 1. This District has the power to tax and to control well spacing and (to some extent) the use of the water. The District also helps monitor water use, pumping levels, water availability, and the long-term implications of expected water use on future water supplies and pumping levels.

The Orange County Water District in southern California illustrates the application of broad local control over groundwater resources. This district has wide ranging powers including the right to levy pump taxes and to require all pumpers to file periodic pumping statements. These powers are employed to regulate both the total quantities as well as the relative amounts of ground and surface water used within the districts.[1]

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[1] Governor's Commission to Review California Water Rights Law, Final Report, pp. 146-147.

This district is not typical, however, as most western groundwater is subject to little control beyond well spacing.

In some situations major improvements in water management are possible through conjunctive management of ground and surface water resources. Generally this involves utilizing surface water supplies when available either for direct delivery to users or to recharge groundwater stocks, which become the main source of supply when the less expensive but fugitive surface waters are insufficient to meet demand. Conjunctive management has been employed by some local water agencies in California for some years. As of 1970, for example, there were 261 groundwater recharge facilities within Central California. The Arvin-Edison Water Storage District, which serves 130,000 acres in Kern County has been particularly effective in conjunctively managing their water supplies. The area has very little natural surface flow but receives water from the federal Central Valley Project (CVP). However, only about 20 percent of their supply from this project is "firm" water as annual deliveries vary from about 10,000 to 350,000 acre-feet. Yet, this district has been able to increase its supply of firm water to 180,000 acre-feet by storing water in its aquifers through artificial recharge during periods of large water receipts from the CVP.[1]

Efficiency of Groundwater Use

Farmers' costs have been the principal regulator of western groundwater use. Once a well is installed, farmers maximize profits by pumping until the marginal cost of pumping equals the marginal revenue that can be attributed to the use of the water. The marginal costs of pumping are essentially the costs of the energy to run the pump. These costs did not provide much of a deterrent to pumping until the early 1970s. Consequently, there has been little incentive to conserve water until recently. As is detailed in section 5, the rise in energy costs over the past decade have encouraged groundwater irrigators to introduce a variety of water-saving innovations.

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[1] Governor's Commission to Review California Water Rights Law, Final Report, pp. 155-156.

These cost increases as well as groundwater users' ability to control the quantity and the timing of their water are important factors underlying the fact that groundwater generally is more efficiently used than surface water in western irrigation. Nevertheless, it does not follow that western groundwater resources are used efficiently. Both institutional constraints and market deficiencies may result in an inefficient use or allocation of groundwater.

Groundwater resources are likely to be used at an inefficiently rapid rate if left to market forces because of several factors. Environmental externalities, which are one possible source of market breakdown, are discussed in Section 6. Another problem results from the cone of depression in the water table that appears in the vicinity of an operating well. Where pumps are closely spaced, this cone increases pumping depths of neighboring wells. But since a farmer does not voluntarily take into account the impacts of his pumping on others, uncontrolled pumping and well spacing can lead to a situation where the social cost of pumping exceeds the private cost. Regulations on well spacing imposed in most western states are designed in part to limit these distortions. Consequently, well spacing is not a major source of inefficiency in most of the West.

The more important source of inefficiency in groundwater use occurs when groundwater tables are falling over time. Individual farmers have no rights to water left in the ground until it is withdrawn. Consequently, the value an individual attaches to water left in an aquifer will be less than its social value, and pumping based on private decisions will use the water at a faster rate than is socially desirable.

At least in theory, a tax on pumping equal to the user cost, or the value of water in storage, would equate marginal private and social costs of pumping and result in an optimum use of the groundwater over time. As simple as this policy seems, two problems have prevented significant use of such a tax. First, almost any tax will be resisted by those who will have to pay it. Second, it would be very difficult to determine the correct tax. The optimal tax rate would decline over the planning period if the aquifer is being depleted.[1] Well or pumping quotas have been a more politically acceptable means of limiting overpumping since this tends to protect the interests of the early users. From the perspective of achieving a social optimum, there remains the difficult problem of setting the correct quota. The tendency is to attempt to limit pumping to the level of natural recharge so as to preserve the water in the aqifer. But such a policy does not represent an efficient solution either. Nevertheless, a study of Yolo County in California suggests the quota system may better approximate the social optimum than does a policy of unrestricted pumping.[2]

As with surface water, there are institutional constraints to transferring water from irrigation to other uses. For example, the Missouri Basin Power Project which involves constructing three 500 MW generating units in Wyoming has encountered a variety of problems in obtaining about 23,000 acre-feet of water per year for cooling purposes. Part of the water was to be supplied from groundwater rights purchased from a neighboring rancher. The project purchased an option permitting it to use up to 15,000 acre-feet of groundwater per year from two different aquifers beneath the ranch. Test wells showed one of these aquifers contained only modest amounts of water, and while the other aquifer was potentially much more productive, it was being heavily used. To protect prior users in the area, the state engineer limited the power project's annual use to 750 acre-feet from the productive aquifer and 2,000 acre-feet from the other aquifer.[1] If market forces were allowed to operate, the Missouri Basin Power Project would have had no difficulty in securing the needed water. The desired quantities were modest relative to agricultural uses in the area, and energy users can afford to pay much higher water prices than can farmers. The problems faced by this power project do not represent an isolated example. Indeed, institutional constraints on transferring water from irrigation to other uses are perhaps the foremost obstacle to achieving an efficient use of western groundwater resources.

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[1] Jay E. Noel, B. Delworth Gardner, and Charles V. Moore, "Optional Regional Conjunctive Water Management," American Journal of Agricultural Economics, vol. 62, no. 3, August 1980, p. 496.

[2] Noel and coauthors, "Optional Regional Conjunctive Water Management," pp. 489-498.

The importance of the distortions resulting from uncontrolled groundwater use depend on the characteristics of the aquifer. In an aquifer with significant lateral flow, the distortions may be large since the effects of one farmer's actions are spread over a large area. In such cases, the "use it or lose it" view which distorts farmers' decisions regarding surface water use (see the discussion on p. 26) are applicable in part to groundwater. In contrast, there is very little lateral flow within the Ogallala aquifer underlying the High Plains. Accordingly, the principal impacts of groundwater pumping within the aquifer are largely contained within the area underlying the farm doing the pumping.

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[1] The John Muir Institute, Institutional Constraints on Alternative Water for Energy, p. 56. This study provides several examples of institutional constraints to obtaining sufficient water supplies for energy projects.

SECTION 5

THE CHANGING ECONOMICS OF IRRIGATION

INTRODUCTION

The preceding analysis demonstrates that the past expansion of irrigation largely relied on access to inexpensive water which is no longer available for expanding irrigation within the West's most favorable agricultural areas. Not only are the opportunities for expanding irrigation now limited and costly but many long-time irrigators are being confronted with sharply higher water costs. While groundwater users have been especially hard hit, nearly all farmers dependent on pumped water have been adversely affected by rising energy costs.

The overall impact of changing water supply conditions and energy prices on irrigation depends on the decisions of thousands of farmers responding to a wide variety of conditions, prices, and opportunities. Farmers are affected differently and they can be expected to respond differently. Nevertheless, as the qualitative nature of the impacts are similar among certain classes of irrigators, insights as to the likely direction and pace of future changes in irrigation can be gained by illustrating how alternative energy prices and pumping depths affect water costs under specific assumptions.

There is no attempt in this study to provide a comprehensive analysis of the economics of irrigated farming; the focus is on water costs and the impacts of higher water costs on the relative profitability of alternative technologies. The analysis proceeds in several stages. Initially, the impacts of rising energy prices and pumping depths on the cost of getting water to the farm are examined. This is done separately for ground and surface water costs. Then the effects of alternative energy price levels on the costs of delivering water by various irrigation methods from the farmgate or wellhead to the plants are examined. Finally, this cost analysis is used as the basis for assessing the technological responses to rising water and energy costs and drawing conclusions as to the likely changes in the relative profitability of irrigated agriculture.

CONVEYANCE OF WATER TO FARMS

Introduction

Initially, farmers irrigated their land by building crude dams and canals, allowing gravity to carry the water onto contiguous cropland. As the best lands in close proximity to the natural water courses became fully irrigated, more sophisticated dams, reservoirs, and canals were constructed to control and transport water, at times to fields hundreds of miles away. With the introduction of high-speed pumps in the 1930s, many farmers began pumping their water from underground aquifers. Although groundwater is the principal source of on-farm pumped water, irrigators also pump surface water from rivers, streams, and ponds that flow on or by the farm.

The costs of gravity-carried surface water are primarily a function of the capital costs to build the necessary irrigation structures such as dams, reservoirs, and canals. Where water must be lifted onto a higher plain, out of a river basin, or from an aquifer, energy becomes an important cost factor. Groundwater pumping is particularly energy-intensive with the costs of pumping increasing directly with lift.

In 1977 there were an estimated 25.8 million acres irrigated with onfarm-pumped groundwater (16 percent above the 1974 level) and 5.3 million acres irrigated with onfarm-pumped surface water (an increase of only 5 percent since 1974)(see table 5-1). While there are no data on gravity irrigation, the combination of Sloggett's estimates of pumped irrigation and the NRI estimate of total irrigated acreage suggests that 17.3 million acres were gravity irrigated. While reliance on two different sets of data in this manner can produce some highly suspect results, it does provide a rough indication of the relationship between onfarm-pumped water and onfarm gravity irrigation. This distinction is important for examining the impacts of energy costs on profitability. It should be noted, however, that even with onfarm gravity irrigation, pumping may be required at some point to get the water to the farmgate.

Groundwater

As noted in section 3, groundwater became an important water source for irrigation in the 1930s and has been the principal source of new irrigation since the mid 1950s. An important consequence of this expansion has been the mining of some of the region's principal aquifers. In the 1960s and early 1970s, when the rate of mining was rising rapidly, there were concerns about the long-term effects of mining on the viability of irrigation. More recently, however, these somewhat distant concerns of eventual depletion have been displaced by the much more immediate threat that energy prices could make irrigation uneconomical even with much of the water still in the aquifer.

Groundwater mining has two adverse effects on water costs. First, there is the increased pumping lift. On a regional or statewide basis, this may not average more than one to three feet a year, generally signifying a one or two percent per annum increase in pumping lift. On a farm-by-farm basis, however, there is a great deal of variation and an individual irrigator

Table 5-1. Acreage Irrigated with Onfarm-Pumped Water by Source of Water and Farm Production Region (1,000 acres)

Region	Groundwater		Surface Water		Both		Total	
	1974	1977	1974	1977	1974	1977	1974	1977
Northern Plains	6,380	8,977	684	676	186	185	7,250	9,838
Southern Plains	7,770	8,320	1,491	1,569	256	256	9,517	10,145
Mountain	3,587	3,636	1,149	1,206	1,284	1,325	6,020	6,167
Pacific	4,561	4,912	1,725	1,845	0	0	6,286	6,757
17 Western States	22,298	25,845	5,049	5,296	1,726	1,766	29,073	32,907

Source: Gordon Sloggett, "Energy and U.S. Agriculture: Irrigation Pumping, 1974-77," Agricultural Economic Report no. 436, NRED, ESCS, USDA, September, 1979, Appendix Table 2.

may face a more rapidly declining water level. A second effect is the decrease in saturated thickness as the aquifer is mined. As saturated thickness declines, so does well yield. Eventually, additional wells and pumps are needed to maintain the flow. For example, a center pivot distribution system requires a minimum well yield of 600 gallons per minute (gpm). At lower yields, farmers must either adopt a new system requiring less gpm, add to the number of wells, or be satisfied with less than optimum coverage. In Texas where declines in saturated thickness are especially serious, some farmers have installed eight to nine smaller pumps each yielding 75 to 150 gpm to reach adequate output.[1] On farms with a center pivot or other sprinkler system, the decline in saturated thickness and its resulting problems may have a greater impact on water costs than do the increased energy costs resulting from greater pumping lifts.[2]

When water must be lifted several hundred feet, energy costs now tend to be the major component of water costs. The importance of energy costs is evident in tables 5-2 and 5-3. The first table indicates the cost of the energy required to pump 1 acre-foot of water from various depths with alternative fuels and fuel prices. The alternative energy prices were selected to represent actual levels in 1970 and 1980, and projections for 2000, all in 1977 constant dollars. Alternative pumping depths of 100, 200, and 300 feet were considered; this range includes the conditions facing many but by no means all farmers. The assumptions adopted in the subsequent discussion as to fuel costs, pumping depths and other factors are most representative of the High Plains region.

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[1] Personal communication with Gordon Sloggett, Oklahoma State University, February 8, 1980.

[2] A. Sanghi and R. Klepper, "The Economic Impact of Diminishing Ground water Reserves on the Production of Corn Under Center Pivot Irrigation," Journal of Soil and Water Conservation, 32(6); 282-285, 1977.

The efficiency of the pumping system is another important determinant of energy costs. Pumping system efficiency, which is the ratio of the theoretical to the actual energy input for a given water output, is essentially the product of the efficiencies of the pump and the power unit.[1] If properly installed, a new pump should have an efficiency of about 75 percent. The power system efficiency varies widely with the type of engine. Reasonable engine efficiencies are 90 percent for electric, 24 percent for natural gas, and 32 percent for diesel. Overall attainable efficiencies for pumping systems are about 66 percent for electric, 17 percent for natural gas, and 20 percent for diesel.[2] The estimates in table 5-2 assume a 60 percent pump efficiency and all power systems are in average operating conditions. The implications of different pump efficiencies on costs are examined late in this section.[3]

The data indicate that the type of fuel has been as important as the pumping depth in determining a farmer's energy costs. Despite a fourfold rise in price since 1970, natural gas continues to be the least expensive means of pumping. In 1980 natural gas was only half as expensive as electricity, the next least expensive source of energy. Diesel, as a result of rapid price increases in the last two years, is now the most expensive fuel.[1] The real cost of pumping an acre-foot of water 200 feet rose an estimated $6.99 for natural gas, $2.73 for electricity, $10.55 for LPG, and $19.41 for diesel from 1970 to 1980. Cost increases are likely to be even higher over the next two decades. If real energy costs double from 1980 to 2000, as assumed in table 5-2, the energy cost increases of pumping one acre-foot from a depth of 200 feet will exceed $9.00 for natural gas, $17.00 for electricity, $25.00 for LPG, and $30.00 for diesel. Under such circumstances fuel price increases will have a greater effect on the profitability of irrigated agriculture than the additional energy costs due to declining well levels. Indeed, the impact of a doubling of fuel prices is comparable to a doubling of pumping depths.

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[1] With internal combustion engines, the efficiency of the pumping system is likely to be reduced another 5 percent or so because of the gearhead.

[2] Based on a brochure of the High Plains Underground Water Conservation District No. 1, "Overall Pump Plant Efficiency" (undated) and on High Plains Underground Water Conservation District No. 1 and the Texas Department of Water Resources, A Summary of Techniques and Management Practices for Profitable Water Conservation on the Texas High Plains, Report 79-01 p. II-14.

[3] Well efficiency, which is another component of overall system efficiency, also is examined later.

The cost of fuel is not the only consideration in the farmer's selection of an energy source. There is considerable variation in the cost and lifetime of motors powered by different fuels. As table 5-3 demonstrates, electric motors are clearly the least expensive, followed by LPG and natural gas units. Installing, repairing and maintaining a diesel motor is almost three times the comparable cost of an electric motor.

Besides the cost of the power unit, the fixed costs of groundwater pumping include drilling and installing the well and pumps. In 1980, wells cost approximately $35/foot to install. Properly installed, a well extends to the bedrock at the base of the aquifer and will have a lifetime of

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[1] Diesel costs in Nebraska, for example, rose from $.40/gallon in 1978 to $.85/gallon in November 1979. See L. F. Sheffield, "Energy Outlook for Irrigated Agriculture in 1980," Cornhusker Economics, December 2, 1979, Department of Agricultural Economics, University of Nebraska, Lincoln, Nebraska.

Table 5-2. Energy Costs to Pump One Acre-Foot of Groundwater with Alternative Fuels and Fuel Prices

(1977 constant $)

	Energy Costs Under Alternative Fuel Prices			
	Pump Lift (Ft.)	1970	1980	2000
Natural gas	100	1.13	4.56	9.12
	200	2.30	9.29	18.58
	300	3.43	13.86	27.72
Electricity	100	7.52	8.88	17.76
	200	15.03	17.76	35.52
	300	22.55	26.64	53.28
LPG	100	7.32	12.60	25.20
	200	14.65	25.20	50.40
	300	21.98	37.80	75.59
Diesel	100	5.24	14.96	29.92
	200	10.59	30.00	60.00
	300	15.74	44.96	89.92

The technical assumptions such as the amount of fuel and the pressure required to lift an acre-foot of water are based on Gordon Sloggett, Energy and U.S. Agriculture: Irrigation Pumping, 1974-77, September 1979. Other assumptions include a 60 percent pumping efficiency. Fuel costs in 1977 constant dollars are: natural gas ($/mcf) .39 in 1970, 1.58 in 1980, and 3.15 in 2000; electricity ($/kWh), .033 in 1970, .039 in 1980, and .078 in 2000; LPG ($/gal.) .25 in 1970, .43 in 1980, and .86 in 2000; diesel ($/gal.) .28 in 1970, .80 in 1980, and 1.60 in 2000. The 1970 prices for LPG, and diesel are a national average obtained from Agricultural Prices, Annual Summary, June, 1977. The 1970 prices for electricity are a national average obtained from Agricultural Prices, October 1977. The 1970 price for natural gas was obtained by personal communication with Delbert Schwab, OSU. The 1980 prices reflect average prices paid by farmers in Nebraska, Kansas, Oklahoma, and Texas in January 1980. The prices were obtained through phone conversations with officials in those states. Landsberg, et. al., Energy: The Next Twenty Years, 1979, p. 71 conclude that, on average, real fuel prices will double by the year 2000. Although long-term contracts consummated in the last several years suggest natural gas prices may rise faster than the prices of the other three fuels, we have chosen to illustrate the implications of a doubling of all fuel prices rather than attempt to estimate differential rates of increase.

fifty years. A vertical-drive pump is used for groundwater and is located at the bottom of the well. The type of pump and number of bowls are selected to match the conductivity of the aquifer.

When the variable and fixed costs of groundwater pumping are combined (the last column in table 5-3), the advantage of natural gas is evident. The total costs of pumping an acre-foot of water range from $17.39 for natural gas to $40.40 for diesel. If cost alone determined fuel selection, there would be an overwhelming preference for natural gas under the prices assumed in table 5-3. In fact, however, in 1977 natural gas accounted for only 35 percent of the acreage, a slight decline from 1974 (see table 5-4). Furthermore, this percentage is likely to keep declining as farmers find it increasingly difficult to arrange natural gas hookups for new irrigation. Historically, natural gas use for irrigation pumping has been limited by access to a hookup rather than cost factors. Consequently, it is not surprising that 61 percent of the acreage irrigated with natural gas is found in the Southern Plains, historically the major production region for this fuel in the United States.

Electricity accounts for 50 percent of the irrigated acreage served by on-farm pumps, and within the Pacific region virtually all irrigation pumps are electric. Although table 5-3 lists electricity as only the second most economical fuel, in the Pacific Northwest the availability of cheap hydropower has made it by far the cheapest fuel. Electricity also is the most important fuel in the Mountain states (74 percent) and accounts for substantial acreage in the Plains states (25 percent). Despite the 15 percent growth in electricity use between 1974 and 1977 (see table 5-4), expansion has been hindered by the fact that many electric utilities are near capacity and unwilling to add new irrigation customers because of peak-load problems.

Table 5-3 Fixed and Variable Costs for Pumping One Acre-Foot of Groundwater Using Different Fuels in 1980.

(1977 constant $ per acre-foot)

Pumping System	Fixed Cost		Variable Cost		Total cost
	Well	Power Unit	Repair and maintenance	Energy costs for pumping	
Natural gas	3.74	3.75	.61	9.29	17.39
Electricity	3.74	2.35	.07	17.76	23.92
LPG	3.74	3.74	.61	25.20	33.29
Diesel	3.74	5.62	1.04	30.00	40.40

Assumptions: The cost of the well is $24,737. This includes drilling and casing installation, 16" casing including perforations, an 8" pump assembly, and 10" bowls. The well was 300' deep with a 900 gpm capacity, capable of irrigating 320 acres at a rate of 2 feet per acre per year. The cost of power units includes all necessary accessories. The motors were all capable of powering a center pivot system. Power ratings for the units were: natural gas--110 h.p., V-8; electric--100 h.p., 3 phase; LPG 100 h.p., V-8; diesel--90 to 130 h.p., V-8. Fixed costs included depreciation (no salvage value) and interest on average investment (10.5 percent). Labor cost for operation and maintenance of materials (oil filters, etc.) were assumed to be constant for all units except the electrical one which required less maintenance. The Consumer Price Index was used to render costs into 1977 constant dollars. The well, motors and maintenance costs were taken from 1979 sources and were raised to 1980 levels using the implicit price deflator for fixed investment (7.4 percent) for the well and motors and the CPI (11.8 percent) for the maintenance cost. The energy costs assumed pumping from 200 feet. The technical relationship and price assumptions are shown in the footnote to table 5-2.

Sources: The cost of the well was taken from Rodney Sharp, Economic Adjustments to Increasing Energy Costs for Pump Irrigation in Northwestern Colorado, unpublished master's thesis C.S.U., 1979. Power unit and maintenance costs were taken from Leslie Sheffield, "Energy...Is it the Achilles Heel for Irrigated Agriculture?", Irrigation Age, September 1979.

Table 5-4. Acreage Irrigated with Onfarm-Pumped Water by Type of Fuel and Farm Production Region (1,000 acres)

Region	Electricity		Diesel		Natural Gas		LPG	
	1974	1977	1974	1977	1974	1977	1974	1977
Northern Plains	1,573	2,612	1,543	2,914	2,430	3,231	1,553	1,008
Southern Plains	2,007	2,347	151	166	6,742	6,949	509	568
Mountain	4,297	4,500	307	350	1,152	1,104	184	136
Pacific	6,197	6,717	4	9	84	31	0	0
17 Western States	14,074	16,176	2,005	3,439	10,409	11,315	2,246	1,712

Source: Sloggett, Gordon. "Energy and U.S. Agriculture: Irrigation Pumping, 1974-77," Agricultural Economics Report No. 436, NRED, ESCS, USDA, September, 1979, Appendix Table 4.

One option for such cases might be to limit new customers to pumping during non-peak hours.

The most rapid growth has been for diesel fuel which increased by 72 percent between 1974 and 1977. Almost all of this growth came in the Northern Plains, the only area which uses substantial amounts of this fuel. Under the 1980 fuel costs listed in table 5-2, little further growth in diesel use is expected. Diesel fuel prices have jumped dramatically since 1978 and supplies have been erratic especially at vital periods in the growing season.

LPG use has been concentrated in the Plains states. Although its use decreased from 1974 to 1977, prospects for increased LPG use are good largely because of the supply or price problems with the alternatives. LPG prices have not risen as precipitously as either diesel or natural gas (table 5-2), and in late 1979 there was a world surplus of LPG.

Given the relative instability of the world fuel market, it is difficult to make accurate predictions about future trends. Researchers in Nebraska--the state with the most growth in pump irrigation in the last ten years and the most potential for further growth--expect that LPG and electricity will grow in importance.[1] Many farmers are switching from diesel to LPG powered pumps because of its ready availability and lower costs. Some have even installed LPG pumps as backups to their diesel units in case of a diesel shortage. It is projected that irrigators and electric utilities will be able to make suitable arrangements concerning peak load problems, thus allowing for some expansion of electricity use. Natural gas suppliers have relaxed restrictions on adding new customers in some areas, and recent improvements in natural gas supply conditions may result in further opportunities for irrigators to expand their use of this preferred fuel.

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[1] Personal communication with Raymond Supalla, Bruce Johnson, and others. Agricultural Economics Department, University of Nebraska, February 25, 1980.

Surface Water

There are wide differences among surface water costs. Since the original appropriators are not charged for the water itself, the cost differences depend largely on the distance and height the water must be transported to get it to a farmer's field and the extent to which these costs are paid by the farmer. Of the roughly 23 million acres irrigated with surface water, about 25 percent are supplied from onfarm sources and 75 percent from irrigation organizations.[1] The following discussion distinguishes between these types.

Onfarm Sources--

The lowest water costs are enjoyed by farmers with rights to adjacent stream flows or ponds that can be exercised with inexpensive dikes and ditches. Under these conditions, water costs consist essentially of the labor required to operate and maintain the dikes and canals which probably amount to no more than a few dollars per acre-foot. Such farmers are not dependent on the cost or availability of energy or on the charges of irrigation organizations for water. Moreover, these farmers frequently possess some of the most senior rights to western waters, making their supplies secure even during a drought. While the explicit costs to such farmers are not likely to rise significantly, the implicit (or opportunity) costs for using this water will rise if there is a general increase in the scarcity of water and a right to sell the water for other uses.

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[1] As noted on p. 5-3, this 23 million acre figure is a rough estimate at best. The percentage breakdown between onfarm and irrigation organization source is based on 1969 census data (see section 4). Since surface irrigation has not expanded much since that time, these percentages probably are still reasonably accurate.

Irrigation in high valleys and mountain meadows is generally of this type, involving flooding of fields by diverting stream flows through crude dikes. Since water costs are very low and independent of the quantity used, large amounts of water may be applied to relatively low value crops in these areas. Indeed, in view of the short growing season, pasture and hay are the primary uses of water in such locations.

There are about 5 million acres irrigated by pumping onfarm surface water sources.[1] The cost structure for water on such farms is similar to that of groundwater users with two exceptions--surface water pumping lifts are generally much less and the source is less likely to be depleted over time. Nevertheless, although surface water pumpers do not face the problem of drawdown as do groundwater pumpers, they may well be confronted with low stream flows in the growing season. Furthermore, these low flows may be associated with groundwater pumping in the region since ground and surface waters may be interrelated such that water pumped from an aquifer may be replaced by increased infiltration from a river bed. While surface water pumpers are affected by increasing energy prices, these price increases are not as critical because of their shorter pumping lifts. In 1977, the average pumping lift for surface water irrigators in the seventeen western states varied from virtually nothing in Arizona to 150 feet in South Dakota. The average for the West was 29 feet, considerably less than the 165 feet average for groundwater pumping.

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[1] Table 5-1 indicates 5.296 million acres irrigated with onfarm pumping of surface water. Personal communication with Gordon Sloggett, author of the source of that data, indicates that very little of that acreage involved irrigation organizations.

Table 5-5 illustrates the range of energy costs (with different fuels and fuel prices) of pumping water 29 feet. At current fuel prices the costs range from $1.34/acre-foot to $4.35/acre-foot, only about one-sixth of the energy costs for pumping groundwater from 200 feet. Since the nature of the costs and the price assumptions are similar for both ground and surface water pumping, the conclusions regarding preferred fuels also are similar; ranging from least to most expensive (at 1980 prices) are natural gas, electricity, LPG, and diesel. Surface water pumpers also can be expected to shift away from diesel to LPG or, if available natural gas and electricity because of cost and reliability of supply considerations.

Pumped surface water costs can be expected to rise over time, largely in response to energy costs. Nevertheless, the cost of water to farmers with onfarm sources will remain low relative to most ground water users and, as is noted below, relative to many farmers receiving water through irrigation organizations. Future water costs on farms with onfarm sources should pose no problem to the long-term profitability of irrigation in areas with favorable climates and soils. If given the opportunity, however, some of these farmers undoubtedly will find it more profitable to sell their water for non-agricultural uses.

Water Supplied by Irrigation Organizations--

Section 4 examined the types of irrigation organizations that have emerged to deliver surface water to farms lacking onfarm sources. As illustrated in table 5-6, water costs vary widely among irrigation organizations and, in some cases, they vary significantly over time within an organization.

Table 5-5. Energy Costs to Pump One Acre-Foot of Surface Water a Height of 29 Feet with Alternative Fuels and Fuel Prices

1977 Constant $

	Energy Costs Under Alternative Fuel Prices		
	1970	1980	2000
Natural Gas	.33	1.34	2.69
Electricity	2.18	2.58	5.15
LPG	2.13	3.66	7.31
Diesel	1.52	4.35	8.70

Assumes 29 foot lift (represents a weighted average of lift heights for the 17 western states, weighted by number of acres irrigated with onfarm-pumped surface water in each state). The technical assumptions such as the amount of fuel and the pressure required to lift an acre-foot of water are based on Gordon Sloggett, Energy and U.S. Agriculture: Irrigation Pumping, 1974-77, September, 1979. The fuel price assumptions are listed in the note to tables 5-2.

Table 5-6. Water Charges of Various Irrigation Organizations Between 1969 and 1980.

(1977 Constant $ per acre-foot)

Location	1969	1972	1979	1980
California				
Water and Power Resources Service (WPRS)[1]	5.79	5.07	2.92	2.76
Dept. of Water Resources (DWR)				
Entitlement water	--	29.96	--	28.62
Surplus water	--	3.11	--	2.37
Fresno Irrigation District[3]	3.58	--	2.92	--
Lemoore Canal and Irrigation Co.[4]	7.75	--	7.51	--
Colorado[5]	--	--	1.25-6.68	--
Utah[6]	--	--	3.34	--

All prices were converted to 1977 constant dollars using CPI.

[1] The majority of WPRS water in California was priced at $3.50/acre-foot (in undeflated dollars). Eighty percent of their water projects in California came on line between 1952-1956 and their contracts affecting water charges will not be renegotiated until 1992-1996. In the meantime, nominal water costs for WPRS projects will remain unchanged and real costs will decline. (Source: Merv Dehaas, Bureau of Reclamation Office in California.)

[2] DWR in California charges all water users a base price, called the Delta price, measured at the junction of the Sacramento and San Joaquin Rivers. In 1977 dollars this amounted to $11.65/acre-foot in 1972 and $9.51/acre-foot in 1980. There is an additional conveyance cost varying by distance from the Delta. The conveyance cost to Kern County (in 1977 dollars) was $18.31/acre-foot in 1972 and $19.11/acre-foot in 1980. In most years surplus water can be purchased in an amount equal to their entitlement at much lower rates. (Source: Lee Carter of California DWR.)

Table 5-6 (continued)

[3] Fresno Irrigation District assesses water users based on acreage. In return irrigators receive an average of 3 acre-feet a year, the quantity used to compute the acre-foot prices for 1969 and 1979. In the latter year the District received 22 percent of their operating costs from taxes collected from nonwater users with property in the District. (Source: Howard Keck, Fresno Irrigation District.)

[4] These are the prices of water allocated to farmers on the basis of their ownership of shares in the company. Each owner receives one acre-foot per share. If additional water is available, it is sold at a reduced rate which varies from year to year. (Source: Jim Handley, Lemoore Canal and Irrigation Company, July 19, 1979.)

[5] This range of prices charged by Colorado irrigation districts is based on data in Raymond Anderson, "Transfer Mechanisms Used to Acquire Water for Growing Municipalities in Colorado," paper presented to Western Farm Economics Association meeting, July 24, 1978.

[6] Derivation of the Utah rate is explained in the text. The data are from U.S. Department of Interior, U.S. Department of Agriculture, and U.S. Environmental Protection Agency, Irrigation Water Use and Management: An Interagency Task Force Report, June, 1979, p. 55.

The principal costs of these organizations are incurred in the construction and maintenance of dams, reservoirs, and conveyance canals and in the energy required to move the water. As noted earlier, however, in many cases not all of these costs are passed on to the irrigators. The Water and Power Resources Service is the extreme case where subsidies may defray 95 percent or more of actual construction costs. Water rates also may benefit from local tax subsidies and the allocation of some investment costs to other beneficiaries such as flood protection, power, and recreation.

The California Department of Water Resources (DWR) charges the highest water rates listed in table 5-6. In 1980 the state charges to Kern County users for the basic entitlement water were more than ten times the rates WPRS charges California users. Although some state funds are allocated to water projects because of social benefits attributed to flood prevention, navigation, and recreation, the DWR provides irrigation water on a largely nonsubsidized basis. All agricultural users of DWR water must pay a "Delta rate," a charge for water at the junction of the Sacramento and San Joaquin Rivers, plus a transportation charge which is a function of their distance from the Delta. In 1980, the Delta rate for all agricultural water users was $9.51/acre-foot and the transportation charge for Kern County users was $19.11/acre-foot. Thus, users in Kern County paid $28.62/acre-foot for their entitlement water. If available, surplus water can be purchased from DWR in an amount up to one's entitlement, at a flat rate of $2.37/acre-foot. Surplus water generally has been available except during the 1977 drought; since most of these farmers are conjunctive users of ground and surface water, the availability of inexpensive surface water enables them to reduce groundwater pumping. Thus, the average cost of DWR water may be considerably below the $28.62 level, and perhaps as low as $15.50/acre-foot.

The Utah rate represents a composite of costs faced by several irrigation companies. Shareholders in a typical company pay $2.51 to $4.18 for each acre receiving water to cover operation and maintenance costs. For companies carrying on system improvements, additional costs of $6.68 to $10.02 per acre raise the average charge to $11.69 per acre. Assuming an application rate of 3.5 feet per acre, which is typical for the state, these irrigators are paying about $3.34/acre-foot.

Conclusions

The above discussion of surface and groundwater costs focused on what can be considered common situations faced by farmers using different sources for their irrigation water. Undoubtedly, many farmers actually pay costs which are quite different from these situations. Nonetheless, some useful generalizations can be made in comparing the cost of irrigation water from different sources.

Generally groundwater is much more expensive (at least to the farmer) than surface water. For example, just the energy costs of pumping an acre-foot of water from 165 feet (the average pumping depth) with electricity (the most common fuel) were about $14.65 in 1980 (using 1977 constant dollars). The total costs were about $20.80/acre-foot, well above the costs to most surface water users. Furthermore, the gap between ground and surface water costs is likely to increase sharply as energy prices rise and groundwater tables decline.

Farmers in Kern County, California receiving DWR water also are in a relatively disadvantageous position regarding water costs. Currently, they pay much more for water than do their neighbors, especially those receiving federally subsidized water, and the differences in water rates undoubtedly will grow. Delivering state water to Kern County is energy-intensive, and one estimate suggests that DWR entitlement water may cost farmers $70/acre-foot by the mid-1980s in current prices.[1]

The lowest water costs are enjoyed by those with onfarm surface water supplies, especially if gravity can be used to deliver it to the field, and farmers receiving federally subsidized water. Although WPRS intends to adjust its rates for inflation when the forty-year contracts expire, the real costs of their water to farmers will decline for the next fifteen years.

ALTERNATIVE IRRIGATION SYSTEMS

Once the water arrives at the farm, it then must be distributed to the fields for use by the crops. Sloggett's 1977 survey distinguished among four principal methods of distributing water for irrigation--surface distribution and three categories of sprinklers; center pivot, big gun, and "other."[2] About three-fourths of the West's irrigated lands use a surface irrigation system and most of the rest use some form of sprinkler system. Virtually all the farmers receiving gravity-fed surface water supplies employ a surface irrigation system. Surface distribution also is used for 20.5 million of the 32.9 million acres irrigated with onfarm-pumped water. Center pivots and siderolls are the primary sprinkler systems used on the remaining 12.4 million acres (table 5-7). The following discussion of surface distribution methods is applicable to either onfarm-pumped water or gravity-carried sur-

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[1] Based on a statement by Gerald Meral, Deputy Director, California Department of Water Resources, at a workshop on western water issues in New York City, June 16, 1980.

[2] Sloggett, Gordon. Irrigation Pumping, 1974-77, 1979.

Table 5-7 Acreage Irrigated with Onfarm-Pumped Water by Type of Distribution System and Farm Production Region in 1977 (1,000 acres)

Region	Surface	Center Pivot	Big Gun	Other Sprinkler[1]	Total
Northern Plains	5,823	3,178	115	721	9,837
Southern Plains	7,426	775	108	1,837	10,146
Mountain	3,412	1,027	5	1,722	6,166
Pacific	3,821	316	39	2,581	6,757
17 Western States	20,482	5,296	267	6,861	32,906

Source: Sloggett, Gordon. "Energy and U.S. Agriculture: Irrigation Pumping, 1974-77," Agricultural Economic Report no. 436, NRED, ESCS, USDA, September 1979, Appendix Table 3.

[1] Primary component of "Other Sprinkler" is the sideroll sprinkler (personal communication with G. Sloggett, 4/10/80).

face water. The discussion of sprinkler systems, however, relates primarily to onfarm-pumped water.

Surface Distribution

For most surface distribution systems, a farmer digs head ditches, which may or may not be lined, or lays or buries pipe along the higher edge of his farm from which water is conveyed to the field to be irrigated. The wide variations in the efficiency with which these systems deliver water to the field are examined later under reducing water costs. If the farmer is irrigating row crops, siphons or gated pipes, which have openings at regular intervals to match the furrows, are used to transfer water from the ditch to the furrows. For close-grown crops, such as alfalfa and small grains, the land is generally flooded and the field is bounded by levees or borders.

Cost is a major attraction of surface distribution. If the topography of the land and soils is suitable, the initial costs to prepare the land and install the required ditches or pipe are low compared to those associated with alternative irrigation systems. Furthermore, very little energy is required to operate a surface system once the water is delivered to the farmgate or pumped from an aquifer. Usually water is pumped only a small distance from the well or farmgate to the top of the field where gravity is used to distribute the water to the crops.

The primary factors limiting the use of surface distribution are the soil type, topography of the land, the availability of labor, and the cost of water. Since the water must flow across the field, surface distribution is inefficient on sandy soil where the water percolates too quickly. Also, to achieve uniform distribution, the field must be relatively flat. A single person is able to irrigate a maximum of 320 to 640 acres with surface distribution which is only about one-fourth of the acreage that a person could handle with center pivot systems. Nevertheless, the costs of labor in irrigation, which tend to be a small fraction of total variable costs for all systems, are not likely to be the decisive factor in selecting among alternative irrigation systems. However, if a farmer is uncertain that labor will be available when needed, a center pivot may be favored over surface distribution.

It is commonly believed that surface systems are less efficient than sprinklers in getting water to the crops. While this view is almost certainly valid for sandy soils, on heavier soils good water management practices can increase the efficiencies of surface systems to the levels generally attained with sprinklers. The investments required to achieve major improvements in water distribution efficiency are considered below. Of course, the application efficiency--defined as the ratio of the amount of water that is retained in the root zone divided by the amount of water delivered to the soil surface--assumes greater importance as water becomes scarce or expensive. There likely will be an important difference between the efficiency of water use from the perspective of the individual farmer and the system as a whole. For example, while the application efficiency of flood irrigation may be low, the basinwide efficiency will be much higher if most of the runoff reappears and can be used downstream.

Sprinkler Irrigation

Center Pivot Sprinklers--

Center pivot sprinklers, first patented in 1952, were irrigating 5.3 million acres in the West by 1977 (see table 5-7). With a center pivot system, a single sprinkler lateral powers itself in a circle around a fixed pivot. Water is supplied through the fixed pivot. The length of the lateral ranges from 200 to 2,600 feet. Most systems are designed for a quarter section of land (160 acres), but irrigate only 130 acres of that section because of the circular pattern. The systems can be modified with end guns or extensions to reach the unwatered areas.

Center pivot systems have several principal advantages over the conventional surface systems. First, center pivots can be used on hillier land (9 to 10 percent slope) and sandier soil. Second, a center pivot system allows considerable savings in labor. Once a center pivot is properly adapted to its site and the automatic controls are set, one person can irrigate 10 to 15 quarter sections of land (1,300 to 2,000 acres). Finally, as noted above, center pivot sprinklers may improve the efficiency with which water reaches the root zone. With proper calibration an application efficiency of 80 percent is possible with a center pivot system.

The principal disadvantages of center pivot systems involve their capital costs. A center pivot system capable of irrigating 130 acres cost in excess of $37,000 in 1979, excluding the well and pumps. And, as is examined in some detail below, operating a center pivot sprinkler requires considerable amounts of energy.

Big Gun Sprinklers--

Big gun sprinklers, which are synonymous with tow and traveler systems, are used on only 267,000 acres (table 5-7). A big gun system typically consists of one sprinkler with a large output capacity mounted on wheels. The big gun may be towed across the field with a power winch and cable or have its own motor. Although a big gun system is by far the most energy-intensive of the various sprinkler systems, it is an attractive alternative in some situations. The big gun is readily adaptable to smaller, irregular shaped fields, its initial costs are less than those of a center pivot, and it does not have a clearance problem that makes the side-roll system unsuitable for tall crops like corn.

Other Sprinkler--

The "other sprinkler" category is primarily side-roll sprinklers, consisting of a long lateral on wheels. The axle is the sprinkler line itself. These systems do not move while irrigating and must be moved from place to place between irrigations. Consequently, they are more labor-intensive but less capital-intensive than center pivot systems.

Another system which comprises a small part of the miscellaneous sprinkler acreage is drip or trickle irrigation systems. In 1979, trickle systems irrigated 220,000 acres.[1] These systems use plastic tubes and drip emitters to apply small quantities of water frequently in the immediate vicinity of the plant roots. Because so much of the soil is left dry, water use is greatly reduced and application efficiency rates approach 100 percent. However, installation costs exceed $1,000/acre, about two to three times the cost of a center pivot system. Drip irrigation systems also are subject to rodent damage and prone to clogging.[2] Moreover, installation costs would be higher with the narrow spacing required for field crops and the pipes, which are fairly permanent, are difficult to farm around. Consequently, with present water costs, use of trickle systems is limited to high value crops; they are particularly attractive for orchards because less tubing and fewer emitters are required (reducing investment costs).[1]

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[1] "Irrigation Survey, 1979," Irrigation Journal, vol. 29, no. 6, Survey/December, 1979.

[2] High Plains Conservation District No. 1 and Texas Department of Water Resources, A Summary of Techniques and Management Practices, p. II-9.

Mobile trickle systems are recent additions to the range of irrigation systems available to farmers. These involve attaching trail lines with emitters to a mobile system such as a center pivot or side roll sprinkler. The water is then dripped rather than sprayed onto the field. Such a system reduces evaporation losses, which average in excess of 15 percent with center pivots in the High Plains,[2] and requires less pressure, and therefore, less energy, to operate than the traditional sprinkler systems. On the negative side, a mobile drip system is prone to clogging and when attached to a center pivot system poses some threat to the plants and the soil as the trail lines move across the field. Since the system is still very much in the experimental stages, it is too early to accurately assess its potential for use in irrigating the principal row crops as corn and cotton.

REDUCING WATER COSTS

The availability of cheap water was an important determinant not only of the rapid expansion of irrigation but of the technologies adopted on irrigated farms as well. The sharp rise in energy costs in the early 1970s increased farmer concern about the efficiency with which water is used. Even among the irrigators fortunate enough to be insulated from energy cost increases, the general scarcity of western water is increasing the opportunity cost of inefficient irrigation when the farmer has the right and means of transferring water to other uses and users.

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[1] High Plains Underground Water Conservation District No. 1 and Texas Department of Water Resources. A Summary of Techniques and Management Practices, p. II-9.

[2] High Plains Underground Water Conservation District No. 1 and Texas Department of Water Resources. A Summary of Techniques and Management Practices, p. II-8.

As water costs rise, technologies and management practices that conserve both energy and water become more cost effective and often essential to the continued profitability of irrigated farming. Farmers have a wide range of opportunities for responding to high energy and water costs short of abandoning irrigation; opportunities include improving pump efficiency, installing tailwater re-use systems, reducing a sprinkler's operating pressure, irrigation scheduling, improving conveyance efficiency, alternate furrow irrigation, growing crops with lower water requirements or higher returns to water, and reducing the quantity of water delivered to a given crop.

Selection of an irrigation system is often predicated by the particular set of circumstances facing a farmer. As noted above, availability and cost of farm labor, water supply, soil type, topography, field size, and the crops grown are important to the selection of an irrigation system, and indeed, may limit a farmer's feasible choices. The costs of installing and operating the system are also important factors both for selecting the most appropriate irrigation system as well as for determining the overall profitability of irrigation. Rapid increases in energy prices, both past and prospective, alter the relative costs of alternative systems and increase the importance of irrigation in overall production costs. The impacts of alternative energy prices on the costs of distributing water with different irrigation systems are examined below.

Energy and the Costs of Alternative Irrigation Systems

Energy is required to irrigate except where water can be distributed to the crops entirely through the force of gravity. The energy requirements vary widely depending on the system used and the pressure at which it is operated. Table 5-8 illustrates the impacts of higher energy prices and alternative fuels on the energy cost of distributing one acre-foot of water with five different distribution systems. The energy costs range from negligible levels for surface irrigation to sizable sums for the more energy-intensive sprinkler systems. Both the type of fuel and the costs of the fuel have major impacts on the costs of operating center pivot and big gun systems. For example, the difference between the electricity costs for distributing one acre-foot with a center pivot and a surface system increases from $11.28 at 1970 prices, to $13.33 at 1980 prices, and to $26.67 for prices projected for the year 2000; the costs to distribute an acre-foot with a center pivot system at 1980 fuel costs rise from $7.46 with natural gas, to $14.36 with electricity, to $20.38 with LPG, and to $24.25 with diesel.

Because of differences in distribution efficiencies, comparisons among irrigation systems should be based on the costs of delivering a given amount of water to the root zone of the plants. For example, to deliver 14 acre-inches of water to the root zone, a system with a 50 percent application efficiency requires an application of 28 acre-inches while a system with an 80 percent efficiency requires only 17.5 acre-inches. For groundwater, total energy costs of pumping and distributing water through alternative systems depend on pumping depth and relative irrigation efficiencies. The total energy requirements of a gravity flow system may be as high as or higher than those of an energy-intensive distribution system if water must be

Table 5-8. Energy Costs to Distribute One Acre-Foot of Water with Different Distribution Systems and Alternative Fuels and Fuel Prices

(1977 current $ per acre-foot)

	Energy Costs Under Alternative Fuel Prices		
Distribution system	1970	1980	2000
Natural gas			
Big Gun	4.36	17.60	35.20
Center Pivot	1.85	7.46	14.92
Side Roll	1.06	4.26	8.52
Trickle	.39	1.60	3.20
Surface	.13	.54	1.08
Electricity			
Big Gun	28.64	33.84	67.69
Center Pivot	12.15	14.36	28.72
Side Roll	6.94	8.20	16.41
Trickle	2.61	3.08	6.15
Surface	.87	1.03	2.05
LPG			
Big Gun	27.93	48.04	96.08
Center Pivot	11.85	20.38	40.76
Side Roll	6.77	11.65	23.29
Trickle	2.54	4.37	8.73
Surface	.84	1.46	2.91
Diesel			
Big Gun	20.01	57.16	114.31
Center Pivot	8.48	24.25	48.50
Side Roll	4.85	13.86	27.71
Trickle	1.82	5.20	10.39
Surface	.61	1.73	3.46

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[1] Distribution PSI Assumptions: Big Gun (165), Center Pivot (70), Side Role (45), Trickle (15), and Surface (5). Trickle PSI estimate taken from Kuei-lin Chen, Robert Wensink, and John Wolfe, "A Model to Predict Total Energy Requirements and Economic Costs of Irrigation Systems," Presentation to the American Society of Agricultural Engineers, December 1976, Chicago, Illinois, mimeograph, p. 6. Center Pivot PSI estimate taken from Gordon Sloggett, personal communication, February 1980, and all other estimates taken from Sloggett, _Energy and U.S. Agriculture: Irrigation Pumping, 1974-77_, 1979. Other assumptions are listed in the footnote to table 5-2.

pumped from considerable depths and the energy-intensive distribution system has a much higher application efficiency.

Under the assumptions in table 5-9, total energy costs of a gravity distribution system with a 50 percent application efficiency exceed those of a center pivot system with an 80 percent application efficiency for pumping depths of 250 feet or more. These are somewhat extreme assumptions as to comparative efficiencies of the two systems, however. Careful water management, leveling, and lining of canals can improve the application efficiencies of surface systems to 60 or perhaps 70 percent on all but sandy soils. Furthermore, as is discussed below, a tailwater recycling pit can improve the application efficiency of surface distribution to levels achieved with the best managed sprinklers. Of course, additional energy is required to pump water from the foot to the top of the field with a tailwater recycling system. On the other side, 80 percent is close to the maximum application efficiency attainable with a center pivot. In windy locations such as the High Plains, wind evaporation losses alone average more than 15 percent.[1] If the application efficiencies are 70 percent for a center pivot and 60 percent for a gravity flow system, the pumping depths must exceed 850 feet for the energy requirements of the surface system to exceed those of the center pivot.

Improving Pumping System Efficiency

Inefficient pumping systems result in unnecessarily high pumping costs. Recent tests by the High Plains Underground Water Conservation District No. 1

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[1] High Plains Underground Water Conservation District No. 1 and Texas Department of Water Resources, A Summary of Techniques and Management Practices, p. II-8.

Table 5-9. Total Energy Costs to Deliver 14 acre-inches of Groundwater to the Root Zone with Alternative Distribution Systems, Application Efficiencies, Pumping Depths, and Fuels, at 1980 Fuel Prices[1]

	Application Efficiency	Water Applied	Total Energy Costs at Various Pumping Depths 200 ft.	250 ft.	300 ft.
	(%)	(acre-inches)	(1977 current $)		
Natural Gas					
Center Pivot	70	20.0	27.92	31.78	35.64
	80	17.5	24.43	27.81	31.18
Surface[2]	50	28.0	22.86	28.26	33.67
	60	23.3	19.04	23.54	28.05
Electricity					
Center Pivot	70	20.0	53.53	60.93	68.33
	80	17.5	46.84	53.31	59.79
Surface[2]	50	28.0	43.83	54.19	64.55
	60	23.3	36.52	45.15	53.78
Diesel					
Center Pivot	70	20.0	90.40	102.89	115.39
	80	17.5	79.10	90.03	100.97
Surface[2]	50	28.0	74.02	91.52	109.01
	60	23.3	61.67	76.26	90.83

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[1] Total energy costs include the energy of pumping the water to the surface based on assumptions of table 5-2 and the energy of distributing the water to the root zone based on assumptions of table 5-8.

[2] Surface irrigation assumes no tailwater recovery system. If a tailwater recovery system is installed and the application efficiency of the surface system rises to 75 percent, then it would take a pumping depth of over 2,000 feet for the energy costs of the surface system to exceed those of the center pivot system.

in Texas showed some farmers paying twice or even three times as much for irrigation fuel as necessary. The main areas for improving pumping system efficiency involved the sizing, staging, and condition of the pump. Specifically, over-sized pumps were a major source of inefficiency. Commonly, the pumps had been designed years earlier to handle larger quantities of water than the well was now capable of yielding. Other sources of energy loss included improper staging to accommodate changes in water levels or additional lift requirements of newly installed sprinkler systems and reliance on worn-out pumps. The condition of the power unit especially with natural gas internal combustion engines, was occasionally the source of some inefficiency, but these problems were not as severe as those involving the pumps.[1]

Table 5-10 illustrates the importance of pump efficiency on the cost of pumping one acre-foot of water a height of 200 feet. Energy costs rise 40 percent as the pump efficiency declines from 70 to 50 percent and costs rise another 67 percent if pump efficiency falls to 30 percent. At 1980 energy costs (deflated to 1977 constant dollars), a 50 percent pump efficiency costs a farmer an additional $3.19 per acre-foot of water with natural gas and $6.09 per acre-foot with electricity compared to the costs with a 70 percent efficient well.

An inefficient pump commonly can be upgraded to a 70 percent efficiency level by selecting the correct number and size of bowls to fit the aquifers conductivity. In early 1980, purchasing and installing new bowls cost from

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[1] High Plains, Underground Water Conservation District no. 1, The Cross Section, vol. 26, no. 12 (Lubbock Texas, December 1980).

Table 5-10. Energy Costs to Pump One Acre-Foot of Groundwater 200 feet with Alternative Fuels, Fuel Prices, and Pump Efficiencies

(1977 constant $)

	Pump Efficiency	Fuel Price 1970	Fuel Price 1980	Fuel Price 2000
Natural Gas	70	1.97	7.96	15.93
	50	2.76	11.15	22.30
	30	4.60	18.58	37.16
Electricity	70	12.88	15.22	30.45
	50	18.04	21.31	42.62
	30	30.06	35.52	71.04
LPG	70	12.56	21.60	43.20
	50	17.58	30.24	60.48
	30	29.30	50.40	100.80
Diesel	70	9.08	25.71	51.43
	50	12.71	36.00	72.00
	30	21.18	60.00	120.00

All technical and cost assumptions except for the pump efficiencies are based on the assumptions of table 5-2.

$1,800 to $2,500 per well.[1] If such an investment improved pump efficiency from 50 to 70 percent, the energy savings would repay the cost in 1.9 to 2.6 years if natural gas at 1980 prices is used to pump 300 acre-feet per year. The payback period would have been shorter with any of the other fuels at 1980 price levels.

Improving Well Efficiency

The efficiency of the overall system for getting water from the ground to the surface also depends on the efficiency of the well. A properly designed well allows maximum withdrawal of water with a minimum of drawdown in the immediate well vicinity. Well efficiency is measured as a ratio of the theoretical drawdown for a given output of water (computed from the aquifer's hydraulic characteristics) and the actual drawdown. Although well efficiencies should not drop below 80 percent, apparently the majority of wells in the Texas High Plains are considerably below this level.[2] Poor well design increases the pumping lift and may result in pumping entrained air and sand. These problems in turn may cause rapid plugging and premature wear of the pump bowls and the pump. Thus, over time an inefficient well hastens the decline in the efficiency of the pumping system which, as noted above, leads to sizable increases in pumping costs. Lyle indicates that a well can be overhauled at approximately one-fourth to one-third the cost of a new well, or $8-$12/foot.[3]

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[1] Personal communication of James Hanson with W. B. Lyle, Agricultural Engineer, Texas Tech, February 15, 1980.

[2] High Plains Underground Water Conservation District No. 1 and Texas Department of Water Resources, Summary of Techniques and Management Practices, p. II-14.

[3] Personal communication with W. B. Lyle, Texas Tech., Agricultural Engineering, February 15, 1980.

The increase in energy prices over the past decade have provided large incentives to overhaul inefficient wells and pumping plants. In many cases the resulting savings in energy costs are sufficient to recover the investment within just a year or two. And the potential savings will grow as energy costs increase, pumping depths rise, and the quantity of water pumped from the well expands. In addition to these cost savings higher crop yields may be possible because farmers are able to apply more water in a timely fashion to their fields when pump yields are higher.

Tailwater Recovery Systems

Ideally, all water applied to the soil should be absorbed into the root zone. Unfortunately, this does not occur because water is lost to evaporation, runoff, or deep percolation. The application efficiency for gravity water systems vary widely depending in large part on the soil type and grade of the land. Runoff is a major cause of low application efficiency in many surface systems. This water, however, can be captured for reuse with a tailwater recovery system. The water is captured and stored in a pit at the end of a field from where smaller pumps can be used to pump the water back to the fields. The energy savings to the farmer can be substantial since tailwater recovery requires only about one-seventh the energy required to pump the same amount of water from a depth of 200 feet. Recovery pits are generally only practical with surface systems. Sprinklers can be adjusted so that their water output better matches the soil infiltration rate, so runoff is reduced.

Table 5-11 indicates the savings in energy costs resulting from installation of a tailwater recovery system that improves application efficiency from 50 percent to 75 percent when the alternative is pumping additional

Table 5-11. Total Energy Costs to Pump and Distribute 14 Acre-Inches of Groundwater to the Root Zone Using Surface Distribution With and Without a Tailwater Recovery System, for Alternative Fuels at 1980 Costs

	Application Efficiency	Energy Cost (1977 Constant $)	Years to Recover $5,000 Investment Costs Using Energy Savings
Natural Gas			
Gated Pipe without tailwater recovery	50%	22.86	--
Gated Pipe with tailwater recovery	75%	16.72	5.0
Electricity			
Gated Pipe without tailwater recovery	50%	43.83	--
Gated Pipe with tailwater recovery	75%	32.00	2.6
Diesel			
Gated Pipe without tailwater recovery	50%	74.02	--
Gated Pipe with tailwater recovery	75%	54.04	1.6
LPG			
Gated Pipe without tailwater recovery	50%	62.22	--
Gated Pipe with tailwater recovery	75%	44.79	1.8

Gated Pipe with tailwater recovery system has following energy costs: 1) the cost of pumping 18.67 ac. in. from 200 ft. at 60% efficiency, 2) pumping 9.33 ac. in. from a reuse pit (1/7th cost of pumping from 200 ft.), and 3) the cost of distributing 28 ac. in. through a surface system at 5 PSI. Installation cost of $5,000 to build a tailwater reuse pit. Gated Pipe without Tailwater Recovery System has following energy costs: 1) the cost of pumping 28 ac. in. from 200 ft. at 60% efficiency, and distributing 28 ac. in. through a surface system at 5 PSI. Other assumptions are listed in the footnote to table 5-2.

Source: Installation costs for the tailwater recovery system are from Rodney Sharp, "Economic Adjustment to Increasing Energy Costs for Pump Irrigation in Northeast Colorado". Master's thesis submitted to Department of Economics, Colorado State University, Fort Collins, 1979.

groundwater from 200 feet. Such improvements in efficiency are attainable where runoff has been a major problem. For all four fuels, energy costs are reduced by about 27 percent. The $5,000 cost of installing a tailwater recovery pit for a 160-acre field would be recovered with the energy savings in only 1.6 to 2.6 years for diesel, LPG, and electricity at 1980 energy prices. The cost-recovery period is five years with natural gas.

Reducing Pressure Requirements for Center Pivots

One of the disadvantages of the center pivot system as illustrated in table 5-8 is its energy intensity. This is particularly true of the initial systems which required pressures of approximately 70 pounds/square inch (PSI) to operate. The rise in energy prices has prompted the development of systems that operate at 20 to 30 PSI. As noted in table 5-12 the energy savings per acre range from about $7 with natural gas to over $22 with diesel. Thus, the savings range from $910 to $2,860 per season for each 130 acres irrigated.

The low pressure systems are not without problems, however. Under the lower pressure, the water comes out in larger droplets instead of the fine mist produced by the high pressure systems. These droplets can cause difficulties under some circumstances. For instance, on soils that have slopes greater than 2 percent (and are not sandy), it is difficult to use center pivots with a PSI requirement much less than 50 to 55 because of increased runoff from the big droplets. The larger droplets increase both erosion and the variability of water application, thereby reducing yields. Systems which require 50 to 55 PSI provide much lower energy savings, and may not justify the high cost of conversion. Unless a farmer needs a new center pivot, the costs of converting engines, pumps, and center pivot can range

Table 5-12. Energy Costs for Pumping and Distributing 14 Acre-Inches of Groundwater to the Root Zone Using Center Pivot Systems with Different PSI and Alternative Fuels in 1980

(1977 current $)

	Natural Gas	Electricity	Diesel	LPG
Center Pivot (70 PSI)	24.43	46.84	79.10	66.47
Center Pivot (25 PSI)	17.45	33.38	56.38	47.36
Savings in energy costs	6.98	13.46	22.72	19.11

Technical relationships and price assumptions are listed in the footnote for tables 5-2 and 5-8. The pumping lift is 200 feet.

between $4,000 to $5,000.[1] Also, if the center pivot system is water driven, then high pressure (65 to 75 PSI) is required to move the system and conversion is not even possible.

Irrigation Scheduling

Formerly it was fairly common for farmers to apply more water than could be effectively used by the plant. The costs of such profligacy are not limited to the costs of the excess water. Excessive irrigation increases erosion and the loss of nutrients in the root zone and, in some instances, may have reduced crop yields. Yet, these costs were either unknown or ignored by farmers as long as water was inexpensive.

High energy and water costs have led to more careful scheduling of water applications. Some improvements were readily attained as cost considerations led farmers to eliminate obvious waste such as shutting off their pumps before the roads surrounding their fields were flooded. But the potential for improved scheduling extends well beyond what is likely to be gained through reliance solely on common sense and intuition. By limiting water applications to the times and quantities that can be used most effectively by the plants, often water use can be reduced while yields are increased.

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[1] Personal communication with Paul E. Fischbach, University of Nebraska, Lincoln, August 21, 1980.

Irrigation scheduling services have emerged in many areas of the West to assist farmers with irrigation decisions. Typically, these services utilize computers to analyze data affecting water needs. A farmer provides the service with information on the crop grown and the soil type. With daily weather records and technical information on soil moisture capacity and levels, infiltration and evaporation rates, and the water needs and responsiveness of particular crops, a computer calculates evapotranspiration and crop water requirements and recommends the timing and rate of water applications. Currently, most scheduling services charge $4 to $5/acre which includes a field inspection by trained personnel. If the service results in reduced pumping, much of this charge could be recovered by savings in fuel costs. For example, under the assumptions of table 5-11, a 25 percent reduction in fuel use for a system combining gated pipe distribution with tailwater recovery would justify a $4/acre cost regardless of the fuel used. In most instances, irrigation scheduling offers greater cost savings where sprinklers are used. And if improved timing of the water applications also increases yields, scheduling becomes even more attractive to farmers. Unfortunately, scheduling services are not available to many farmers, and they only help when a farmer can control the timing and quantity of water use.

Onfarm Conveyance Systems

Surface irrigation commonly involves delivering water from the well or farmgate to the fields through unlined ditches and siphon tubes. This method results in very low application efficiencies which can be improved by about 16 percent by installing underground pipe to convey water to the field's edge and using gated pipes to deliver it to the furrows. The cost of such an arrangement depends largely on the distance which the water must be conveyed and the configuration and number of lateral pipes. A configuration designed to irrigate field crops in the Texas High Plains uses 20 feet of pipe per acre at a cost of \$62.74 per acre.[1] A gated pipe system proposed for field crops in northeast Colorado uses over 48 feet of pipe per acre and costs \$120 per acre.[2] Assuming the irrigator is pumping groundwater from 200 feet and applying 28 inches per acre, a 16 percent increase in efficiency from adopting an underground and gated pipe system would save annually \$3.67 per acre with natural gas, \$7.01 with electricity, \$9.95 with LPG, and \$11.85 with diesel. The cost (excluding interest) of the less expensive system would be recovered in 5.3 years by the irrigator using diesel fuel; 6.3 years with LPG; 9.0 years with electricity, and 17.2 years with natural gas. Recovering the cost of the more expensive system would take nearly twice as long. At times the federal government has provided cost-sharing funds for onfarm water conservation construction. The availability of such funding, of course, would make investments in improved conveyance systems more attractive to farmers.

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[1] This system is described in James E. Osborne, Alan M. Young, Otto C. Wilke, and Charles Wendt, Economic Analysis of Trickle Distribution Systems-Texas High Plains, Texas Agricultural Experiment Station, Texas A&M University, October 1977. The system covers 96 acres, using 1,637 feet of underground pipe and 12 twenty-foot spans of gated aluminum pipe. Total cost is \$6,023.

[2] This system is described in Rodney Sharp, "Economic Adjustment to Increasing Energy Costs for Pump Irrigation in Northeast Colorado," a Master's thesis submitted to the Department of Economics, Colorado State University, Fort Collins, 1979. This system covers 300 acres using 3,960 feet of connecting pipe and 10,560 feet of gated pipe. The total cost is \$36,000.

Alternate Furrow Irrigation

Experiments suggest water use can be decreased by almost 33 percent by irrigating alternate furrows instead of every furrow. Most of the water savings, however, occur on the lower part of the field. The resulting unequal water distribution can adversely affect yields, perhaps outweighing the savings in water costs. As energy prices increase and research improves the technology, alternate furrow irrigation may become increasingly widespread.

Switching Crops

Crops vary in their requirements for and sensitivity to water. Thus, as water becomes more expensive, farmers can be expected to switch to crops requiring less water or providing higher returns per unit of irrigation water.

Corn requires a "full" irrigation to obtain high yields and does not yield well under reduced levels of irrigation. In the High Plains region 20 to 28 acre-inches are typically applied. Sorghum, wheat, and soybeans, on the other hand, do not require as much water as corn and retain most of their yielding ability when irrigation is reduced. Farmers typically apply 12 to 16 acre-inches of water to sorghum. While relative prices and yields continue to make corn the predominant irrigated grain crop, high water costs in the southern High Plains have prompted some switching out of corn in recent years and these substitutions could become much more common.[1]

Irrigated soybeans are still relatively insignificant in the West. However, soybeans use 2 to 4 acre-inches less water than corn and, in recent years, prices for soybeans have averaged three times the levels of corn prices. Until now, soybean yields have not been very responsive to irrigation; however, experiments with a dwarf variety in Nebraska show irrigated yields in the range of 65 bushels per acre compared to dryland yields of about 30 bushels per acre.[2] These yield increases together with high energy prices could make soybeans an attractive alternative to corn on irrigated lands in eastern Nebraska.

In the High Plains irrigation increases wheat yields by about 50 percent compared to the 300 and 150 percent increases common with irrigated corn and sorghum respectively. Irrigated wheat, however, does have some advantages which could lead to its future expansion. As noted, wheat does not require as much water as corn. Since winter wheat is grown largely in the offseason, in locations where the growing season is long enough, irrigated wheat may be expanded without installing a new pump or abandoning another crop. Furthermore, irrigated wheat can be grazed by livestock and still grown out for its grain without much loss of yield.[3]

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[1] Ronald G. Cummings, "Scenarios for 1985 Grains/Soybeans Production in the High Plains Area." Unpublished report prepared for Resources for the Future, 1978, p. 43.

[2] Personal communication with Ray Suppalla, Bruce Johnson and others, University of Nebraska, Agricultural Economics Department, February 25, 1980.

[3] Personal communication with Herbert Grubb, Texas Water Development Board, February 28, 1980.

Local researchers suggest the following trends in cropping patterns are likely. In the north Texas High Plains where irrigated corn is now grown, irrigated sorghum and irrigated wheat will displace corn as energy prices and pumping lifts continue to increase.[1] In Nebraska, high water costs or limits on water withdrawals, would prompt a substitution of irrigated sorghum for irrigated corn in the western part of the state and irrigated soybeans for corn in the east. Currently, about 92 percent of Nebraska's irrigated acreage is in corn. While changes in crop mix may reduce water withdrawal and pumping costs, crop prices are a key variable for any permanent change in cropping patterns.

Reducing Water Applications Below Yield Maximizing Levels

In addition to the opportunities discussed above for improving irrigation efficiency or switching to less water intensive crops, a farmer may reduce water costs simply by applying less water. Indeed, for any given crop and irrigation system, the quantity of water that maximizes farm profits declines as the cost of the water rises.

Agricultural scientists have tended to focus their efforts on obtaining maximum yields. A principal concern of irrigation research has been to determine the quantity and timing of water flows that maximizes the yield of a given crop. The emphasis on physical yield has been reinforced by irrigation management services, both public and private, which almost invariably base their water use recommendations on yield maximizing criteria. Yet the quantity of water that maximizes physical yields is the same as the quantity that maximizes farm profits only if the cost of water is zero. Where water is inexpensive, the differences between these two water quantities are slight. For example, one study suggests that the difference between the profit and yield maximizing water applications is two acre-inches or less for cotton and wheat with water costing $6 per acre-foot. But when water costs increase 5 to 10 fold, profit maximization calls for applying 4 to 14 acre-inches less water per acre than the yield maximizing levels.[1]

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[1] Herbert Grubb, February 28, 1980.

Of course, neither the farmer nor the researcher knows with precision how crop yields in a given year will respond to varying water levels. The response undoubtedly varies among farms. Nevertheless, higher water prices are likely to prompt lower water applications which, other things being equal, generally reduce yields and thus irrigated production.

Future Technological Change

The above discussion focused on adjustments with existing management skills and technology. Future technological innovation also will help farmers offset the impacts of higher water and energy prices. One area with great potential involves developing crop varieties requiring less water. When water was inexpensive, research emphasized increasing yields regardless of the water applied. Only within the last decade or so have researchers paid much attention to developing varieties for irrigation that can use less water without reducing yields. The change in research emphasis that has come with rising water costs undoubtedly will bring at least marginal improvements in the ability of plants to produce with less irrigation water. However, scientists still have only a very incomplete knowledge of the factors affecting the efficiency of plant transpiration and resistence to drought. Sizable gains in yields to water may have to await further development of this basic knowledge which may require several decades. While such knowledge will provide farmers the means of increasing the returns to irrigated water, it also should improve the productivity of dryland farming in the semiarid West. The net result might well be an increase in the relative productivity of dryland compared to irrigated agriculture in this area.

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[1] The study cited is reported in Harry W. Ayer, Paul G. Hoyt, and Melvin Cotner, "Crop-Water Production Functions in Economic Analysis," Irrigation and Drainage Today's Challenges, ASCE, 1980, pp. 336-345.

Technological advances likely will improve the effectiveness and profitability of many of the cost-reducing and yield-increasing techniques discussed above. Further advances in computerized irrigation scheduling, new or better designed irrigation methods such as perfecting a mobile trickle system for use on the principal irrigated crops, or improving water flow through row damming, and development of evaporation suppression methods and chemicals will enable farmers to make more effective use of scarce and expensive water supplies. A water-efficient irrigation system of the not too distant future may automatically schedule the quantity and timing of irrigations based on a computerized system which assimilates detailed information on soil moisture derived from a neutron probe and the crop's responsiveness to water at each point in its productive cycle. A neutron probe measures the hydrogen ions in the soil which are directly related to the quantity of water in the soil.[1]

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[1] David Sheridan, Desertification of the United States, Council on Environmental Quality, 1981 (Washington, GPO), p. 113.

Research to develop salt-tolerant varieties and farm management techniques appropriate for irrigating with low quality water supplies will limit yield losses in areas where salinity levels are rising and may expand the water supplies suitable for irrigation to include brackish and highly saline waters.[1] Hail suppression techniques and improved wind breaks may reduce crop losses and, thereby, increase returns to water. And advances in weather modificiation may increase the useful water supplies for both irrigated and dryland farming in the West. This listing is not intended to be exhaustive but merely suggestive of the range of relevant research that undoubtedly will expand the capability of western farmers to respond effectively to rising water and energy costs.

PROFITABILITY OF IRRIGATED AGRICULTURE

While the focus of this analysis is on water costs, these costs are just one element of farm profitability. Factors such as farm management, weather, soil, crop prices, and the prices of other inputs are all important determinants of the return to irrigated agriculture. Nevertheless, it is the control over water that distinguishes irrigated from dryland farming and the cost of the water is a crucial determinant of the relative profitability of irrigated and dryland agriculture.

The impact of higher water and energy costs on the profitability of growing alternative crops in various regions of the West are illustrated with the aid of the 1977 crop budgets developed as part of the U.S. Department of Agriculture's Firm Enterprise Data System (FEDS). These budgets, which are developed from surveys, represent averages for the farms surveyed in each region. Thus, the data reflect local production costs, crop prices, yields, and water sources and costs. There are, of course, other factors affecting farmers' cropping plans that are not reflected in these budgets. Crops may be grown as part of a rotation designed to preserve productivity, reduce erosion or control pests, or they may be complementary to other aspects of the overall farm enterprise. For our purposes, however, the profitability measures in the FEDS do illustrate important factors influencing the impact of water and energy prices on the course of irrigated agriculture in the coming decades.

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[1] Salinity problems are examined in section 6.

Table 5-13 shows net returns and irrigation costs for several crops in several western regions. With a single exception, the illustrated surface water costs are much less than the groundwater costs. The exception is cotton grown in south central California where the surface water costs include the cost of pumping a considerable height and distance from the Delta. The average (with equal weights for each region) surface cost across crops and regions is $17.16/acre-foot, less than half the average groundwater cost of $38.28/acre-foot. Consequently, water costs tend to be a significantly higher percentage of total production costs for groundwater users. For the four crops and twelve locations, water costs as a proportion of total production costs averaged 22 percent for surface water and 38 percent for groundwater.

Under the assumptions of table 5-13, cotton and corn tended to be the most profitable crops. Profitability, however, varies widely depending on location, and relative profitability depends only in part on differences in water costs. The profitability rankings are consistent with a priori

Table 5-13. Water Costs, Yields, Crop Prices and Returns for Several Crops and Locations, 1977

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		Water[2]					Net Returns ($/acre) to	
	Location[1]	Source	Cost ($/ac. ft.)	Ac.-Ft. applied	Yield[3] (bu/acre)	Price[3] ($/bushel)	Land, management, overhead, risk[4]	Risk[5]
Corn	Central California (400)	S	12.00	3.75	119.1	3.36	187.76	55.80
	Eastern Nebraska (500)	C	27.72	1.00	107.4	2.62	143.17	55.72
	South Western Nebraska (200)	C	26.40	1.67	108.3	2.62	125.66	32.17
	Texas Panhandle (100 & 200)	C	45.60	2.17	109.8	3.04	115.14	73.58
	Eastern Kansas (200 & 300)	C	31.44	1.75	105.3	2.69	107.00	62.35
	Western Kansas (100)	C	36.12	2.00	106.8	2.69	91.75	44.40
Sorghum	Central California (400)	S	15.84	2.08	70.4	3.13	51.92	-40.39
	Texas Rio Grande (600)	S	12.84	1.50	59.3	2.67	42.33	- 3.72
	Eastern Nebraska (500)	C	26.04	1.00	75.5	2.38	82.30	18.45
	Eastern Kansas (200 & 300)	C	31.44	1.33	80.2	2.38	64.54	27.44
	Texas Panhandle (100)	C	43.20	1.83	84.3	2.67	63.38	23.01
	Western Kansas (100)	C	36.12	1.50	76.0	2.38	46.02	15.35
	Arizona (200)	C	26.32	3.17	66.1	3.07	14.56	-82.27
Winter wheat	Central California (400)	S	17.16	1.17	72.9	3.63	146.22	57.66
	Snake Basin (Id.) (400)	S	9.12	2.50	62.9	3.50	128.52	44.31
	Arizona (200)	S	20.88	3.33	70.2	3.39	53.31	- 3.56
	Columbia Basin (Wash.) (401)	C	47.76	1.50	77.0	3.83	132.82	23.92
	Eastern Oklahoma (300)	C	49.32	1.00	32.5	3.60	23.68	-20.18
	Western Kansas (100)	C	35.16	1.17	36.8	3.41	24.34	-13.86
	Texas Panhandle (100)	C	42.84	1.33	28.8	3.55	-16.91	-71.74
Cotton	S. Central California (300)	S	36.24	3.33	1014/lbs. lint 1635.5 lbs. seed	.621/lbs. lint .063/lbs. seed	294.56	154.28
	Texas Rio Grande (600)	S	12.84	1.50	472.3/lbs. lint 748.8/lbs. seed	.472/lbs. lint .052/lbs. seed	- 9.84	-94.53
	Arizona (200)	C	40.20	4.92	1127.8/lbs. lint 1887.2/lbs. seed	.597/lbs. lint .061/lbs. seed	268.55	149.61
	Central Texas (300)	C	34.92	2.00	416.0/lbs. lint 648.0/lbs. seed	.480/lbs. lint .052/lbs. seed	40.59	-30.94
	Texas Panhandle (200)	C	58.80	1.17	351.7/lbs. lint 568.7/lbs. seed	.472/lbs. lint .052/lbs. seed	26.71	-32.40
	Eastern Oklahoma (300)	C	48.36	2.00	509.0/lbs. lint 810.0/lbs. seed	.437/lbs. lint .056/lbs. seed	13.02	-46.16

Source: U.S. Department of Agriculture, Economic Research Service. "Farm Enterprise Data System (FEDS)", computer printouts prepared in cooperation with and available from the Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma.

[1] The numbers in parentheses are the FEDS area identification numbers for the respective states.

[2] Water costs include fixed and variable costs. The sources are S for surface water and C for groundwater.

[3] Crop yields and prices are region-specific averages for 1974-1977 calculated from FEDS data. Crop prices are adjusted to 1977 dollars.

[4] Returns to land, management, overhead and risk are calculated as the difference between total receipts and the sum of total variable costs and the depreciation, taxes, interest, and insurance on machinery and equipment. Costs are based on 1977 FEDS budgets adjusted to the 1974-77 average yields.

[5] Returns to risk also deduct land charges, management, and overhead from total receipts. Land charges are calculated as either cash rents, share rents, or are based on land prices. Management charge is calculated as 10 percent of all costs except land. Overhead reflects costs for building and fence repairs, accounting, telephone, farm organization dues, and other such costs.

expectations based on the acreage planted to the various crops. Corn is both the dominant crop in terms of acreage and relative profitability in the Plains States; cotton, which is important in western Texas, Arizona, and California, is profitable in these areas; and irrigated wheat, which is the primary irrigated grain grown in the Northwest is profitable in that region. In contrast, irrigated wheat is generally unprofitable and not very important in the Plains. Differences in regional net returns to wheat are due largely to yields which averaged 32.7 bushels/acre in the three High Plains locations compared to 70.9 bushels/acre in California, Idaho, and Washington.

The impacts of rising energy costs and pumping lifts on relative profitability are illustrated in table 5-14, which compares the returns to risk of the major irrigated and dryland crops in a region under alternative cost assumptions. The cost alternatives are selected to depict possible changes in pumping depths and energy prices between 1977, 1980, and 2000. Four comparisons are provided: irrigated corn compared to dryland corn in eastern Nebraska, irrigated corn compared to dryland wheat in both western Kansas and north Texas High Plains, and irrigated cotton compared to dryland cotton in the south Texas High Plains. The irrigated alternative was more profitable than the dryland at all four locations with the 1977 pumping and cost assumptions (table 5-14). However, if pumping depths and energy prices increase over time according to the assumptions and all other factors affecting profitability are unchanged, then the dryland alternative becomes increasingly attractive relative to the

Table 5-14 Returns to Irrigated and Dryland Farming in Selected Locations with Alternative Energy Costs and Pumping Lifts[1]

	1977			1980			2000		
	Irrigated	Dryland	Difference (Irrigated-dryland)	Irrigated	Dryland	Difference (Irrigated-dryland)	Irrigated	Dryland	Difference (Irrigated-dryland)
Eastern Nebraska[2]	(corn)	(corn)		(corn)	(corn)		(corn)	(corn)	
Return to L,M,O,R ($/acre)[6]	143.17	35.89	107.28	138.45	32.44	106.01	121.88	23.70	98.18
Return to risk ($/acre)	55.72	-22.55	78.27	51.00	-26.00	77.00	34.43	-34.74	69.17
Water costs ($/ac.-ft.)	27.72			32.40			48.96		
Western Kansas[3]	(corn)	(wheat)		(corn)	(wheat)		(corn)	(wheat)	
Return to L,M,O,R ($/acre)[6]	91.75	45.41	46.34	78.60	42.35	36.25	30.66	35.21	- 4.55
Return to risk ($/acre)	44.40	16.29	28.11	31.25	13.23	18.02	-16.69	6.09	-22.78
Water costs ($/ac.-ft.)	36.12			42.72			66.72		
North Texas High Plains[4]	(corn)	(wheat)		(corn)	(wheat)		(corn)	(wheat)	
Return to L,M,O,R ($/acre)[6]	115.14	17.33	97.81	108.52	14.75	93.77	77.80	8.71	69.09
Return to risk ($/acre)	73.58	- 4.47	78.05	66.96	- 7.05	74.01	36.24	-13.09	49.33
Water costs ($.ac.-ft.)	45.60			48.72			62.88		
South Texas High Plains[5]	(cotton)	(cotton)		(cotton)	(cotton)		(cotton)	(cotton)	
Return to L,M,O,R ($/acre)[6]	26.71	20.19	6.52	20.04	14.28	5.76	- 3.42	2.26	- 5.68
Return to risk ($/acre)	-32.40	-35.14	2.74	-39.07	-41.05	1.98	-62.53	-53.07	- 9.46
Water costs ($/ac.-ft.)	58.80			64.56			84.60		

Source: USDA, Firm Enterprise Data System, 1977.

[1] Between 1977 and 2000, energy prices increased according to assumptions made in table 5-2, pumping depths increased according to the cropping situation description, and all other factors affecting profitability are left unchanged. Water costs are based on fixed and variable costs. Fixed and variable costs (excluding energy prices and pumping depth) remained unchanged between 1977 and 2000. Yields and prices are averages of 1974-1977 FEDS data.

[2] Eastern Nebraska: Irrigated corn (107.4 bu/A) vs. dryland corn (45.7 bu/A). Irrigation water (12 ac.-in.) was pumped from 100 ft. and distributed through gated pipe using electricity. Pumping depth increased .5 ft./year. Corn prices: $2.62 bushel.

[3] Western Kansas: Irrigated corn (106.8 bu/A) vs. dryland wheat (25.7 bu/A). Irrigation water (24 ac.-in.) was pumped from 215 ft. and distributed through gated pipe using natural gas. Pumping depth increased 2 ft./year. Corn prices: $2.69 bushel; wheat prices: $3.41/bushel.

[4] North Texas High Plains: Irrigated corn (109.8 bu/A) vs. dryland wheat (13.6 bu/A). Irrigation water (26 ac.-in.) was pumped from 200 ft. and distributed through gravity flow system using natural gas. Pumping depth increased 3 ft./year. Corn prices: $3.04 bu. Wheat prices: $3.55/bushel.

[5] South Texas High Plains: Irrigated cotton (351.7 lbs. lint/A and 568.7 lbs. seed/A) vs. dryland cotton (230.3 lbs. lint/A and 366.2 lbs. seed/A). Irrigation water (14 ac.-in.) was pumped from 150 ft. and distributed thorugh gravity flow system using natural gas. Pumping depth increased 3 ft./year. Cotton prices: $.472/lbs. lint and $.052 lbs. seed.

[6] Returns to land, management, overhead, and risk.

irrigated alternative. In two of the locations with significant groundwater mining, western Kansas and south Texas High Plains, the dryland alternatives are more profitable in the year 2000.

Crop prices are assumed to remain unchanged throughout the time period covered in table 5-14. Altering this assumption shows that relatively modest increases in crop prices can compensate for expected increases in pumping costs. Changes in crop prices necessary to cover the increase in water costs due to greater pumping depths and higher energy prices from 1977 through 2000 are 20¢/bushel for corn in eastern Nebraska, 46¢/bushel for corn in western Kansas, 35¢/bushel for corn in north Texas High Plains, and 7.8¢/pound for cotton lint in the south Texas High Plains.

The preceding discussion of profitability overstates the likely impacts on irrigated agriculture by not allowing for adjustments to cost changes. Many farmers already have made major adjustments to higher energy and water costs by adopting some of the water savings techniques discussed above. And over the next several decades, new technologies will provide farmers with an even wider range of options for adjusting to higher water costs.

Crop price levels are also an important determinant of the relative profitability of irrigated and dryland farming. Higher crop prices, of course, increase the profitability of all farming. But since irrigated yields tend to be higher than dryland yields, the impacts of a given change in crop prices are greater with irrigated farming. For example, the assumptions of table 5-14 suggest irrigated corn yields in eastern Nebraska are more than double the yields from the region's dryland corn alternative. If water costs double from the 1977 base year level in that region, a 45¢/bushel or 17 percent increase in corn prices would be sufficient to restore the base level profit differential between irrigated and dryland corn production in the region. Higher corn price increases would increase the relative returns to irrigated production despite the doubling of water costs.

The example of cotton in the south Texas High Plains suggests that in some cases rising water costs may require much larger compensating crop price increases to restore the relative profitability of irrigated farming. Water costs are higher in the Texas High Plains than in eastern Nebraska and the assumed differential between irrigated and dryland cotton yields are not as high as the corn differential (see table 5-14). Consequently, a doubling of water costs on the irrigated cotton alternative would require a doubling of cotton lint and cotton seed prices to restore the base year differential between the profits of irrigated and dryland cotton.

Consequently, the impacts of rising energy and water costs on the relative profitability of irrigated and dryland farming will depend largely on the adjustments farmers can make to changes in relative factor prices and the level of crop prices. In the absence of higher crop prices, the available technological adjustments to higher energy and water costs are unlikely to be sufficient to prevent some decline in the profitability of irrigated relative to dryland farming. On the other hand, if the sharp increases in agricultural prices predicted by some analysts are realized,[1] the returns to western irrigation may increase faster than those to western dryland farming. Nevertheless, limited water supplies would prevent these higher returns from being translated into a rapid expansion of irrigated acreage in the West.

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[1] For example, the Global 2000 report concludes that real food prices will double by the year 2000. Council on Environmental Quality and the Department of State, The Global 2000 Report to the President: Entering the Twenty-First Century, Vol. 1, p. 2.

SECTION 6

ENVIRONMENTAL IMPACTS OF IRRIGATED AGRICULTURE

NATURE OF THE PROBLEMS

Erosion and the unintended impacts of fertilizer and pesticide use are the principal environmental problems associated with dryland farming, and uncontrolled water movements are their primary cause. Even though irrigation implies some control over water, similar environmental problems stemming from excessive water applications are not uncommon on western irrigated lands. When large quantities of water are applied, either naturally or artificially, then soil, fertilizers, and pesticides may get transported into streams and rivers or nitrates get leached into the groundwater. Both the farmlands, where soil and nutrients are lost, and the recipient water bodies, where the quality of the water deteriorates, are damaged in the process.[1]

In addition to the unintended transport of soil, fertilizers, and pesticides, there are several environmental problems peculiarly associated with irrigation. These are salinity and the problems related to stream flow reduction, groundwater mining, and water development projects.

All water used for irrigation carries salts and the salt content of the water increases as water evaporates, is consumed by the plants, or passes over saline soils. Salts both in the water and the soil create problems for agriculture; they inhibit plant growth and in extreme cases render the land useless for agriculture. Where drainage is adequate, salts can be flushed from the root zones if there is sufficient rainfall or additional irrigation water is applied for this purpose. But this seldom eliminates the salinity problem. If the salts are washed off the land with additional water applications, the return flows have higher salt concentrations. This may adversely affect the plant and wildlife dependent on the river as well as downstream users. In areas lacking good drainage, repeated irrigation may raise the water table. If the water table reaches the root zone of the plants, capillary action carries water close to the soil surface, where it evaporates and leaves a salt residue. In time this process, if uncorrected, greatly reduces or even destroys the productivity of the land. In addition, salinity increases management and operating costs and accelerates corrosion of equipment.

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[1] See Pierre R. Crosson and Kenneth D. Frederick, The World Food Situation: Resource and Environmental Issues in the Developing Countries and the United States, Research Paper R-6, Resources for the Future, 1977. Chapter 5 describes the nature of the environmental impacts.

As the areas's major water consumer, irrigation is the primary contributor to the depletion of western river and stream flows. About 90 percent of the nearly 90 billion gallons of water consumed per day for offstream uses is for irrigation. As a result many former perennial streams are now dry or reduced to a trickle for much of the year. As stream flow declines, pollutant concentrations and temperatures rise. Both can have devastating effects on riverine flora and fauna. Moreover, the flow of fresh water into estuaries and tidal marshes is diminished, reducing the productivity of these ecologically vital and commercially valuable resources. Lagoons on the Texas and California coasts have been particularly vulnerable to such damage.[1]

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[1] U.S. Water Resources Council, The Nation's Water Resources, 1975-2000; Second National Water Assessment, December 1978, vol. 2, part II, p. 73.

In addition to its impact on pumping costs and future water supplies, groundwater mining may result in subsidence or salt water intrusion. The costs stemming from subsidence become particularly important when settled areas are affected. For example, subsidence due to groundwater withdrawals in the Houston-Pasadena-LaPorte areas of Texas and in Las Vegas has reached the point where city streets and buildings are threatened. Saltwater intrusion occurs when the fresh water of coastal aquifers is mined and replaced by seawater. As a wedge of saltwater intrudes into the aquifer, the value of the remaining freshwater as well as the storage value of the aquifer may be destroyed. Saltwater intrusion is a problem along parts of both the California and Texas coasts.

There are also important environmental impacts associated with water projects. The dams, reservoirs, and canals required for large-scale surface irrigation projects have major impacts on ecological systems. Such projects commonly flood valuable lands, reduce downstream sediment loads, and alter the timing and quantity of river flows to the detriment of the riverine ecology. Unintended consequences may include loss of animal habitats and potentially damaging effects on coastal fisheries. In developing countries large water projects often have lead to spread of waterborne diseases, especially schistosomiasis. All such impacts should be taken into account in evaluating the environmental implications of irrigation projects.

The environmental impacts of irrigation are not all negative. In arid and semiarid areas irrigation may produce a better vegetative cover which in turn reduces erosion and runoff. Irrigation may either reduce or increase the amount of sediment in the water. In the High Plains, for example, irrigation has helped reduce wind erosion which has been a serious problem during periods of extended drought. These beneficial effects, however, often have been countered by the removal of windbreaks to make room for large sprinkler systems. From a national perspective, irrigation has greatly expanded the land base suitable for high productivity agriculture; the high yields generally attained on irrigated lands enable some highly erodable lands to remain under permanent vegetative cover. Changes in the overall level of irrigation affect the total number and the location of the cropped and pastured acres required to produce a given output. Since the marginal lands that would be brought into production with any general expansion of dryland farming are apt to be environmentally fragile, the level of irrigation has important implications for the nature, location, and magnitude of the environmental impacts associated with national agricultural production.

The direct environmental impacts of irrigated agriculture can be divided into (1) those such as salinity, erosion, and water quality degradation from fertilizers and pesticides associated with onfarm water management, and (2) those such as low flows, subsidence, saltwater intrusion, and the need for water development projects associated with the overall demands irrigation places on limited water supplies. Our focus in this section is on the first group--the impacts that stem from and might be controlled by the water management practices of farmers. Of course, improved on farm water management may reduce the water withdrawn and consumed for irrigating a given acreage and, thus, might increase stream flows, and reduce subsidence and saltwater intrusion. On the other hand, any such water savings might be diverted to other offstream uses as expanding the irrigated acreage or other water-consuming activities rather than increasing instream flows. The environmental issues associated with the overall level of irrigation and water use are considered in the concluding section in the context of examining the implications of alternative irrigation trends on the overall environmental impacts of U.S. agriculture. Analysis of the environmental impacts of low flows, subsidence, saltwater intrusion, and water projects is beyond the scope of this study.

EXTENT OF THE ENVIRONMENTAL PROBLEM

Salinity

Salinity is the most pervasive environmental problem stemming from irrigation in the United States. All western river basins except the Columbia are confronted with high and generally rising salt levels. In much of the Lower Colorado, parts of the Rio Grande, and the western portion of San Joaquin river basins, the salt concentrations in either the water or the soils are approaching levels that threaten the viability of their traditional forms of irrigated agriculture. Groundwater salinity, which may result from the infiltration of irrigation waters or from the intrusion of seawater as the fresh water is pumped out of coastal aquifers, is not a widespread problem in the West. Sea water intrusion results from the overpumping of groundwater and the lowering of water levels in aquifers that are in hydraulic continuity with the ocean. Overpump may occur from any type of well--municipal, industrial, or irrigation. However, the problem is growing and already is serious in parts of California, New Mexico, Montana, and Texas.[1] Although groundwater tables are less susceptible than surface waters to pollution, the problems are much more difficult to correct underground.

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[1] See U.S Department of Interior, Westwide Study Report on Critical Water Problems Facing the Eleven Western States, April 1975, pp. 116-118 and U.S. Water Resources Council, The Nations's Water Resources, 1975-2000. vol. 1, summary, p. 65.

A rough but informed guess suggests that 25 to 35 percent of the irrigated lands in the West have some type of salinity problem, and the problems are getting worse.[1] Two large irrigated areas where salinity already is a serious problem are the Lower Colorado River Basin and the west side of the San Joaquin Valley in California. The underlying cause of the problem differs in these cases. In the Colorado the salt content of the river increases progressively downstream due to the salt-concentrating effects of irrigation and the addition of salts picked up as the water passes over saline formations. About two-thirds of the salts delivered to the Colorado are from natural sources, and these deliveries only can be eliminated through expensive investments to divert the river and its tributaries around some of the areas contributing the salts or desalinization plants. Irrigation accounts for most of the remaining salts which could be curtailed greatly by reducing irrigation return flows. Annual damages from salinity in the Colorado River have been estimated between $75 and $104 million in 1980 and $122 and $165 million in 2000 if no control measures are taken. While most of the damages would be incurred by municipal and industrial users, farmers would face decreased crop yields, increased leaching requirements, and higher management costs. Four initial control projects costing a total of $125 million have been proposed.[2]

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[1] Personal conversation with Jan van Schilfgaarde, Director, U.S. Salinity Laboratory, Riverside, California, February 1980.

[2] U.S. Department of Interior and U.S. Department of Agriculture, Final Environmental Statement: Colorado River Water Quality Improvement Program, vol. I, May 1977, section 1.

In the San Joaquin Valley the principal salinity problem results from poor drainage preventing salt-laden waters from being carried away from the fields. High water tables already threaten the productivity of about 400,000 acres and ultimately more than 1 million acres in the Valley may be similarly affected. A $1.26 billion drainage system to carry irrigation runoff from the western side of the Valley to the Delta has been proposed as a solution to the problem. Since farmers would have to install their own underground drainage to get the waters to the central drain, the total costs of an effective system would be considerably higher than this figure.[1]

Erosion and Sedimentation

Erosion and sedimentation are viewed as problems in many areas of the West. With a few exceptions, however, it is not clear that irrigation is an important contributor to these problems. Even though human activities altering the natural ground cover may greatly accelerate erosion and sedimentation, in the eleven most western states "most of the rapidly eroding range, grassland and forest-covered soils occur where natural geologic erosion is dominant."[2] The human contribution to erosion probably has been more important in the Plains States, but as noted earlier the impacts of irrigation are mixed.

On the positive side, in dry areas irrigation may provide a better vegetative cover to protect the soil from the wind. Also, land leveling, which may be done with the installation of an irrigation system, reduces erosion, and irrigation may reduce sediment in streams where the natural loads are heavy.

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[1] U.S. Department of Interior, California Department of Water Resources, and California State Water Resources Control Board, San Joaquin Valley InterAgency Drainage Program, Final Report, June 1979.

[2] U.S. Department of Interior, Westwide Study Report on Critical Water Problems Facing the Eleven Western States, April 1975, p. 127

On the negative side, center pivot irrigation has led to cropping hilly, sandy soils that are highly erodable and the wheel tracks of the large mobile sprinkler systems may lead to the start of large gullies. Some of the soils that were placed under irrigated crops become extremely vulnerable to wind erosion if irrigation is terminated. Since the high cost of water in the southern High Plains has forced some farmers to eliminate winter irrigation for a cover crop, wind erosion has been increasing.[1] But the most extensive erosion from irrigation arises when flood and furrow systems are used on lands which have not been adequately leveled.

While there are no data on leveling, the 1977 National Resources Inventory differentiates between crop and pasture lands which are and are not susceptible to erosion and indicates how much of the acreage in each subclass was planted to various crop groups and how much was irrigated by gravity and pressure systems. Tables 6-1 to 6-3 summarize some of these data for farm production regions.

In 1977, 35 percent of the West's irrigated cropland and 34 percent of the irrigated pasture was in subclass e, that is, susceptible to erosion; 21 percent of the cropland and 28 percent of the pasture was highly erodable (see table 6-1). The percentages of irrigation on erodable lands varied widely among states with Oklahoma (69 percent) and Washington (57 percent) at the high end and Arizona (1 percent), Nevada (2 percent), and California (8 percent) at the low end. While the NRI data suggest that erosion may be a problem on many of the lands irrigated in the West, the potential

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[1] Personal Communication with Herbert Grubb, Texas Department of Water Resources, February 28, 1980.

Table 6-1. 1977 Irrigated Cropland and Pasture on Erodable Soils, by Farm Production Region

	Cropland		Pasture	
	Erodable acres irrigated (1000)	% of all irrigated cropland	Erodable acres irrigated (1000)	% of all irrigated pasture
Northern Plains:				
erodable[a]	4,405	41	41	33
highly erodable[b]	2,599	24	23	19
Southern Plains:				
erodable[a]	4,076	47	183	46
highly erodable[b]	2,055	24	140	35
Mountain:				
erodable[a]	5,713	38	750	38
highly erodable[b]	3,772	25	625	32
Pacific:				
erodable[a]	2,160	18	320	23
highly erodable[b]	1,391	12	274	20
17 Western States				
erodable[a]	16,354	35	1,294	34
highly erodable[b]	9,817	21	1,062	28

Source: U.S. Soil Conservation Service, 1977 National Resource Inventory, Revised February 1980 edition, tables 3a and 4a for appropriate region.

Definitions:

[a] Erodable includes all subclass e lands. These are defined as those soils where susceptibility to erosion or past erosion damage is the dominant problem or hazard in their use.

[b] Highly erodable includes class III-e soils or worse. Class III-e soils have moderately steep slopes and are highly susceptible to water or wind erosion or have suffered severe erosion in the past.

Table 6-2. 1977 Irrigated Row Crops on Erodable Soils, by Farm Production Region

	1000 acres	% of irrigated row crops	% of total irrigated-erodable or highly erodable cropland
Northern Plains:			
erodable	3,510	41	80
highly erodable	2,002	23	77
Southern Plains:			
erodable	3,143	53	77
highly erodable	1,423	24	69
Mountain:			
erodable	1,690	41	30
highly erodable	924	22	24
Pacific:			
erodable	305	7	14
highly erodable	52	1	4
17 Western States:			
erodable	8,648	37	53
highly erodable	4,401	19	45

Sources and definitions are identical to table 6-1.

Table 6-3. 1977 Use of Gravity (Flood or Furrow) Irrigation on Erodable Soils, by Farm Production Region

	1000's acres	As % of that category
Northern Plains:		
erodable[a]	1,375	30
highly erodable	498	19
Southern Plains:		
erodable	2,315	53
highly erodable	787	35
Mountain:		
erodable	4,380	64
highly erodable	2,828	60
Pacific:		
erodable	835	33
highly erodable	590	35
17 Western states:		
erodable	8,905	49
highly erodable	4,703	41

Source: U.S. Soil Conservation Service, 1977 National Resources Inventory, February 1980 edition, table 9a of appropriate region.

[a] Definitions of erodable and highly erodable are included in the notes to table 6-1.

problems are much more extensive on dryland cropland, 64 percent of which was in subclass e.

A comparison of the Soil Conservation Service's 1967 CNI and 1977 NRI data suggest the potential erosion problem on irrigated lands increased substantially over the decade. While total irrigated acreage rose by nearly 9.7 million acres or 23 percent, erodable irrigated cropland rose by 5.8 million acres or 50 percent. Irrigated cropland in subclass e rose from 29 to 35 percent of the total. The Northern Plains region, which accounted for nearly 60 percent of the total increase in irrigated acreage, accounted for half of the increase in erodable irrigated acreage. The Southern Plains accounted for 24 percent, the Mountain region 23 percent, and the Pacific region only 2 percent of the total increase in erodable irrigated acreage over the decade. The most dramatic change was in the Southern Plains where subclass e soils rose by 1.4 million acres even though total irrigation in the region grew by only 0.2 million acres.

The threat of erosion depends on the use of the land as well as on its susceptibility to erosion. Since row crops represent the agricultural use most likely to lead to erosion, it is significant that more than one-half of the irrigated-erodable cropland was in row crops (see table 6-2). In 1977, 8.6 million irrigated-erodable acres were planted to row crops and more than half of this land was highly erodable. These data suggest that 37 percent of all irrigated row crops in the West were on erodable lands and 19 percent were on highly erodable lands. The combination of planting row crops on erodable soils is particularly common in the Plains states which accounted for more than three-fourths of the total for the seventeen western states. In contrast, the Pacific region accounted for only 4 percent of the West's total row crops planted on erodable soils.

The type of irrigation system also influences the likelihood of erosion. As noted above, the combination of gravity irrigation on erodable soils is particularly vulnerable to serious erosion. Gravity is the sole means of irrigating 66 percent of the West's irrigated acreage, and on another 4 percent gravity is combined with a pressure irrigation system. Table 6-3 indicates that 49 percent of the erodable irrigated soils (17 percent of all western irrigated lands) and 41 percent of the highly erodable irrigated soils (9 percent of the total) are irrigated with gravity. Nearly half of this acreage is in the Mountain region where 64 percent of the erodable and 60 percent of the highly erodable irrigated acreage uses gravity distribution.

In summary, although the data are not available to link irrigation crop and water management practices directly to the West's overall erosion problems, the data do indicate potential for major problems of erosion on irrigated lands, especially within the Plains and Mountain states. Erosional problems would be site-specific and particularly pronounced under those conditions where the soil is more erosive and the topography more rolling. Proper irrigation management practices should help mitigate the erosion problem. On the other hand, there is twice as much highly erodable land in dryland row crops in the West as there is in irrigated row crops. Moreover, this comparison does not just reflect the larger acreage in dryland crops; 27 percent of the dryland row crops were on highly erodable soils compared to 19 percent of the irrigated row crops.

Agricultural Chemicals

The Second National Water Assessment identifies the principal pollutants of the nation's surface and groundwater supplies. Agricultural chemicals are identified as a "significant" source of surface water pollution in three areas in the West but the Assessment does not indicate whether dryland or irrigated farming is the principal culprit and there are no data to make this distinction. In comparison to the rest of the country, which has twenty-four locations where agricultural chemicals are identified as a significant surface water pollutant, this problem is not very extensive in the West. The only water quality problems directly linked to irrigation return flows by the Assessment are groundwater pollution and surface water salinity, and groundwater pollution is only deemed "significant" in Southern California.[1] Percolating irrigation water has been blamed for leaching large quantities of nitrates into underlying aquifers in Southern California. In the Santa Maria Valley it was estimated that 39 percent of the nitrates applied to irrigated fields were leached below the root zone.[2] Likewise in the Upper Santa Ana Valley, nitrate pollution of groundwater was prevalent, especially under sandy, coarse irrigated soils. While nitrate contamination spreads very slowly, decontamination is equally slow to occur.[3]

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[1] U.S. Water Resources Council, The Nation's Wate[illegible]ces, 1975-2000: Second National Water Assessment, December 1978, vol. [illegible]ary, pp 62-65.

[2] L. J. Lund, J. C. Ryden, R. J. Miller, A. E. Laag, and W. E. Bendixen, "Nitrogen Balances for the Santa Maria Valley," in P. F. Pratt, editor, National Conference on Management of Nitrogen in Irrigated Agriculture, University of California, Riverside, 1978, p. 411.

[3] R. S. Ayers, "A Case Study--Nitrates in the Upper Santa Ana River Basin in Relation to Groundwater Pollution," in Pratt, Management of Nitrogen, pp. 355-367.

The projected expansion of irrigation in the Sandhills of Nebraska poses a potentially serious groundwater pollution problem in that region. Since the soil is quite sandy, agricultural chemicals are easily leached through the soil into the groundwater. The water table averages 100 feet beneath the surface, and where there is irrigation (primarily center pivots), nitrate-N levels have risen to 20 ppm, twice the public health standard for drinking water. With good irrigation management the concentration of nitrates-N are expected to level out around 20 to 25 ppm. But given the sandy nature of the soil, it is unlikely that any lower levels can be maintained with an expansion of irrigation and much higher concentrations are clearly possible.[1]

The emerging pollution problem in the Sandhills is in contrast to many parts of the High Plains where the agriculture chemicals move very slowly through the soil. In the Texas High Plains, for example, there are still no recordable pollution problems in the groundwater after almost forty years of irrigation.[2]

MANAGING ENVIRONMENTAL PROBLEMS

Conceptually, the way to eliminate erosion, sedimentation, and water quality degradation stemming from irrigation is simple--limit the rate and quantity of water applied to a field to levels that can be fully absorbed within the root zone. Without runoff, chemicals and sediment are not washed or leached into neighboring streams, lakes, or aquifers. There is a catch, however, in that reduced runoff may lead to salt accumulations in the soil.

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[1] Personal communication with Darryl Watts, University of Nebraska, July 15, 1980

[2] Personal communication with Herbert Grubb, Texas Department of Water Resources, March 3, 1980.

Moreover, there is no mystery as to the technical means for at least reducing and perhaps eliminating runoff. The most serious problems of erosion and sedimentation are associated with flood and furrow irrigation. Land leveling, and the adoption and proper operation of sprinkler, drip, or subsurface irrigation systems reduce or eliminate runoff. While these technologies are expensive and not always cost effective to farmers, there are a wide variety of other measures that can reduce runoff and help control the resulting environmental damages. These include reduced tillage, altering the length and size of the furrow stream, changing the frequency and duration of irrigations, management of crop residues to reduce erosion and evaporation, controlling the tail waters and sediments at the end of the field, and lining of canals.

The nature of the return flow problems as well as the best methods for handling them vary widely depending on factors such as soil type, land gradient, irrigation technique, water quantity and quality, and drainage conditions. A National Conference on Irrigation Return Flow Quality Management reported on the effectiveness of alternative farming practices for controlling return flow quality under a wide range of conditions.[1] For example, a study of the cost effectiveness of reducing on-farm sediment losses in southern Idaho concluded that, on a cost per ton of sediment saved basis, sediment ponds, vegetative strips, and then mini-basins were the most cost effective. Side-roll sprinklers and flow cutbacks were the most expensive.[1] A more general conclusion from another study of farms in southern Idaho is that any practice which increases irrigation efficiency generally decreases sediment loss. In this particular study a 20 percent decrease in water applied to a gravity irrigated field resulted in an 85 percent decrease in sediment loss.[2] An evaluation of surface irrigation return flows in California's Central Valley concludes that return flows are nearly nonexistent where water is scarce or expensive.[3] Indeed, a general conclusion that might be drawn from these site-specific studies is that the return flow problems are significantly reduced when the cost of the water provides an incentive for efficient use. What comprises efficient use, however, varies widely depending on the specific conditions of the region and even the individual farmer.

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[1] James P. Law, and Gaylord V. Skogerboe, editors, Proceedings: National Conference on Irrigation Return Flow Quality Management, Colorado State University, Fort Collins, Colorado, 1977.

Unfortunately, eliminating runoff will not solve all the environmental problems associated with irrigation. The high rates of water consumption required for plant growth necessarily leave higher salt concentrations. The salts must be deposited somewhere. If water applications are limited to the absorptive capacity of the soil, the salts accumulate in the soil; if additional water is applied to leach the salts out of the root zone, the salts may show up in either the underlying aquifer or the neighboring streams.

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[1] Karl H. Lindeborg, Larry Conklin, Roger Long, and Edgar Michalson, "Economic Analysis of On-Farm Methods for Controlling Sediment and Nutrient Losses," in Law and Skogerboe, Proceedings, pp. 193-201.

[2] D. W. Fitzsimmons, C. E. Brockway, J. R. Busch, G. C. Lewis, G. M. McMaster, and C. W. Berg, "On-Farm Methods for Controlling Sediment and Nutrient Losses," in Law and Skogerboe, Proceedings, pp. 183-191.

[3] Kenneth K. Tanji, James W. Biggar, Robert J. Miller, William D. Pruitt, and Gerald C. Horner, "Evaluation of Surface Irrigation Return Flows in the Central Valley of California," in Law and Skogerboe, Proceedings, pp. 167-173.

Nevertheless, improved farm management techniques can go a long way towards reducing some salinity problems and obviating the need for some of the costly structural solutions under consideration. Efficient water and agronomic management can reduce (but not eliminate) the salt concentrations by limiting evaporation and evapotranspiration. A closer than normal spacing of cotton rows, for example, hastens the maturity of the plant and reduces the time required to develop a full canopy. Consequently early evaporation losses are reduced and the season for evaportranspiration is shortened; the resulting water savings reduce the salt concentrating effects of the irrigation.[1]

Curtailing the water applied for leaching reduces the dissolution of salts from the soil. Downstream users benefit from a reduction in the mass of salt appearing in the drainage water but the farmer is left with higher salt precipitation in his soils. However, research results reported by van Schilfgaarde suggest that the adverse impacts of these salts may be kept within acceptable levels through careful water management. Under some circumstances salinity in the lower portion of the root zone can be permitted to build up considerably more than suspected without adversely affecting yields as long as good quality water is applied in the upper zone.[2]

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[1] A letter from Jan van Schilfgaarde, Director, U.S. Salinity Laboratory, Riverside, California, October 31, 1980

[2] van Schilfgaarde, Jan, "Minimizing Salt in Return Flow by Improving Irrigation Efficiency," pp. 81-98, in Law and Skogerboe, Proceedings.

Since water and agronomic management practices alone will not eliminate the presence of and problems resulting from salts, additional steps may be required to preserve the long-term productivity of irrigated agriculture under many circumstances. Engineering solutions such as basin-wide drainage systems or desalting plants exist but as noted above the costs are high. A promising alternative for many situations is growing plants adapted to high levels of water and soil salinity. Barley has long been grown successfully with salt levels that would kill most plants. And in recent years scientists have developed varieties of wheat and tomatoes with high tolerance to salt. Genetic research to combine salt tolerance, high yield, and desirable market characteristics in a single variety is likely to further expand the opportunities for successful irrigation with saline water and soil and to become increasingly important to the future of irrigated agriculture.[1]

Improved basin-wide water management also has great potential for mitigating salinity problems. Where poor drainage prevents salt-laden waters from being carried away from the field, artificial drainage is required to prevent eventual loss of productivity. But the extent of the drainage needs can be greatly reduced through good management. Van Schilfgaarde suggests that the San Joaquin Valley drainage problem could be reduced to one-third or less of current levels and a long-term equilibrium reached through an integrated irrigation system whereby the best water is used first on salt-sensitive crops with the increasingly salt-laden runoff applied to increasingly salt-tolerant crops. The remaining highly saline waters would be reduced to quantities that could be disposed of through a greatly scaled down drainage system or perhaps in evaporation ponds.[1] A major, if not insurmountable, difficulty in implementing such a scheme would be to get some farmers to accept lower quality water.

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[1] Emanuel Epstein, Jack C. Norlyn, Dale W. Rush, Ralph W. Kingsley, David B. Kelley, Glen A. Cunningham, Anne F. Wrona, "Saline Culture of Crops: A Genetic Approach," Science, vol. 210, 24 October 1980, pp. 399-404.

FEDERAL EFFORTS TO CONTROL IRRIGATION RUNOFF AND SOME POLICY LESSONS

Although there had been a long history of water quality legislation, it was not until passage of the Federal Water Pollution Control Act Amendments of 1972 (FWPCA) that the federal government was granted the power and mandate to pursue specific water quality goals. Under the FWPCA, water quality control was based primarily on setting effluent standards for point source discharges. Polluters were required to have permits for the discharge of pollutants, and target dates were established for the adoption of improved treatment technologies. The federal legislation required each state to develop a water quality control program; once a state's program is approved by the Environmental Protection Agency (EPA) as being consistent with federal provisions, administration of the permit system is turned over to that state.[1]

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[1] Personal communication with Jan van Schilfgaarde in February 1980 and October 1980.

Congress recognized that control of point sources of pollution would not be sufficient to meet the established goals. Thus, section 208 of the Act charged the states with developing and implementing "areawide waste treatment management plans" which also were to include "a process to (i) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution...and (ii) set forth procedures and methods (including land use requirements) to control to the extent possible such sources;"[2]

The first federal initiative to control the quality of irrigation return flows stems from the 1972 Act. The legislation was not clear as to whether agricultural pollutants were to be classified as point or nonpoint sources. This was left up to EPA. In July 1972 EPA ruled that irrigation return flows from sources of less than 3,000 acres were exempted from the permit requirement unless the EPA Regional Administrator or the head of a state water pollution control agency identified a particular source as a significant polluter. The EPA ruling, which was prompted in part by the administrative difficulties of attempting to issue permits to all point sources, was challenged in court by the Natural Resources Defense Council. In July 1975 the court upheld the challenge and ordered EPA to extend the permit system to include all agricultural point sources.

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[1] This discussion of federal water quality control is based largely on George E. Radosevich and Gaylord V. Skogerboe, Achieving Irrigation Return Flow Quality Control Through Improved Legal Systems, EPA-600/2-78-184, December 1978, section 7.

[2] Federal Water Pollution Control Act Amendments of 1972, Report No. 92-1465, House of Representatives, 92 Congress, 2 sess. (1972).

Partly in response to this court decision, a series of EPA actions between February 1976 and February 1977 classified most agricultural water pollution as nonpoint sources. Irrigation return flows through ditches and drains to navigable waters were an exception; these were to be subjected to general rather than individual water pollution control permits. Subsequent legislation changed this and placed all agricultural return flows under the 208 planning process, which has yet to make significant progress in curbing the water quality damages from irrigated farming.

During the period of the 1970s when it appeared irrigation discharges might be classified as point sources and be subject to the permit system, six states issued permits for irrigation return flows. These permits, however, were used only for monitoring (not for controlling) discharges.[1] Nevertheless, just the hint of federal regulation was sufficient to prompt challenges to their legality. The permits generally were for irrigation districts. But in most cases the only effective way to control the discharges is at the farm level, and the authority of irrigation districts to control onfarm water management through discharge permits is uncertain at best. Legal issues almost surely will stymie attempts to control irrigation discharges in this manner.

A step towards establishing a firmer legal basis for farm-level water quality control has been made in California and Oregon where water quality provisions have been attached to new, extended, or transferred water rights.[2]

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[1] Radosevich and Skogerboe, Achieving Irrigation Return Flow Quality Control, p. 119.

[2] Ibid, p. 117.

While it is desirable to attach quality considerations to new and altered water rights, this represents a slow and piecemeal approach to controlling return flows and will be inadequate for meeting most water quality objectives.

Even if there were no legal issues associated with a permit system, there are questions as to the practicality of designing and enforcing on-farm water management regulations. Conditions vary so much among farms and regions that blanket standards will be extremely inefficient and costly. Yet, government agencies lack the specific knowledge of the relationships between farming practices, soils, weather conditions, and water quality to design an efficient and effective system for achieving predetermined water-quality objectives. Furthermore, the number of actors is so large and the distances among them so great that it would be extremely difficult and costly to enforce effectively any permit system without the cooperation of the farmers.

The voluntary approach to controlling the quality of irrigation return flows generally starts with a recognition that success depends on gaining farmer cooperation. Amidst the confusion that followed the Federal Water Pollution Control Act Amendments of 1972 regarding responsibility for controlling agricultural irrigation discharges, several states did initiate projects designed to encourage farmers to adopt better water and farm management practices. Two states, Idaho and Montana, developed demonstration projects to show how improved conservation and management practices can reduce erosion and sedimentation. The most comprehensive effort to develop and implement a voluntary approach has been in the Sulphur Creek area of the

State of Washington. This project relies primarily on education and technical assistance to encourage farmers to adopt best management practices; regulations on farmers may be used at a later date only if and where a voluntary approach does not work. The program is structured to provide local control to meet the program's objectives of conserving soil and water and improving water quality, fertilizer and pesticide application, and crop production. Initial results suggest that attitude changes stemming from improved education and information and reliance on local inputs and control are key elements in reducing pollution discharges. It is too soon, however, to assess the effectiveness of the program in controlling environmental damages.[1]

As long as the desired changes are in the farmers' interests, education, technical assistance, and demonstration projects are likely to be extremely effective means of inducing innovation. But since the environmental benefits of innovation are external to the farm, the educational approach alone may not be sufficient to induce farmers to adopt the most socially desirable practices. On irrigated farms, the gap between the farmers' and society's benefits and costs are likely to be great if water is inexpensive. In such cases additional inducements are required to encourage adoption of water management practices that will reduce discharges and their associated environmental problems. A variety of financial incentives and disincentives might be used to promote improved water management, but the most direct and effective is likely to be through the cost of water. Where water is expensive, runoff and the associated environmental problems tend to be very small. There is a strong correlation between the irrigation practices that are profitable when water is expensive and those that are advisable for reducing the environmental damages. As the economic analysis of section 4 illustrates, expensive water makes it economically advantageous for farmers to adopt practices such as tailwater recovery systems, sprinkler irrigation, and irrigation scheduling. With these practices farmers can reduce the intake of water to levels more in line with the water needs of the crops. This in turn reduces discharges which are the major source of the environmental problems of irrigated farming.

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[1] John Spencer, Marc Horton, and Jim Gleaton, "The Sulphur Creek Pilot Project: A Practical Approach to Control of Pollutants Leaving Irrigated Farmlands," in Law and Skogerboe, Proceedings, pp. 307-319. A more recent assessment of the Sulphur Creek project was provided by Marc Horton in a July 1980 conversation with the author.

As was noted in section 4, many surface water irrigators are insulated from the forces pushing up the social cost of water in the West. Consequently, such farmers have little incentive to adopt improved water management practices. Any effort to raise the cost of water to these farmers would meet with strong resistance as well as legal obstacles. However, improved water use on such farms might be encouraged and farmer opposition muted by measures to improve the marketability of water and allow the sale of unused water. While such changes would not increase the price these favored farmers paid for water, they would increase the opportunity costs of using water and, thereby, provide incentive to use it efficiently.

Even when farmers pay market water prices, environmental problems associated with runoff may occur which keep the social costs above the private costs. In most areas, however, the remaining environmental problems are likely to be greatly reduced if not inconsequential. When significant problems persist, they could be addressed by programs designed to meet the problems and conditions of a specific area. With the overall problem reduced in scope, a program focused on the remaining priority problem areas would be much more manageable than any comprehensive effort to control irrigation return flows.

Federal policies have failed to provide any effective control to the quality of irrigation return flows. Radosevich and Skogerboe offer several explanations for this failure. Officials in charge of implementing water quality and water rights laws in the seventeen western states were almost unanimous in the view that "relative to other water pollution problems, degradation from irrigation return flow as a statewide problem is not significant or has not been adequately identified."[1] Many states felt the EPA approach was not workable and others became turned off by the gyrations and uncertainties in the legal treatment of irrigation return flows. And finally, even when there has been agreement that a problem does exist, adoption of a suitable remedy has been deterred by both the physical difficulties of dealing with it and the philosophical resistance to federal controls.[2]

Despite the general lack of success of past efforts to control the quality of irrigation return flows, these efforts do provide some important lessons that could be useful for designing future policies. Considerations that should be taken into account in formulating such policies include: (1) the elusive nature of irrigation return flows makes them very difficult to control with an effluent approach such as permits; (2) there is considerable potential for mitigating environmental damages of erosion and water runoff through improved onfarm management of irrigation water; (3) farmers (along with almost everyone else) act in ways they perceive to be in their own best interests, and environmental costs are ignored in farmer's plans as long as the damages are borne by others; (4) farmers' aversion to controls combined with their large numbers and spatial dispersion make it difficult and expensive to direct farmer behavior through controls; (5) the nature of the problems, their importance, and the appropriate corrective measures vary widely among and within regions, making most national standards and control measures inefficient and costly.

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[1] Radosevich and Skogerboe, Achieving Irrigation Return Flow Quality Control, p. 114.

[2] Ibid, p. 124.

Analysis of past efforts and the problems confronted led Radosevich and Skogerboe to develop and advocate an "influent control approach" to irrigation return flow quality control which relies primarily but not exclusively on incentives to encourage voluntary compliance.[1] Their approach calls upon the states to undertake the following eight steps. (1) Designate problem areas for focusing the state's efforts and an area entity (such as an existing irrigation organization) that would be responsible for monitoring, discussing ways to alleviate unreasonable water quality degradation, and encouraging voluntary changes in agricultural practices by those farmers identified as significant sources of pollutants within the designated problem area. (2) Develop standards and criteria for beneficial use of water that are consistent with the state's concept of a water right. (3) Introduce incentives to use water more efficiently. Incentives might be in the form of cost-sharing funds and technical assistance for improvements in on-farm water management or permitting and encouraging the trading, leasing, or selling of water saved through the adoption of more efficient irrigation practices. (4) Include water quality provisions in new, transferred, or changed water rights. (5) Adopt and enforce a reporting and recording system for water rights in order to improve a state's ability to manage water quality. (6) Recognize that some reasonable degradation of water quality will result from agricultural water use and that it would be excessively expensive and detrimental to irrigation to completely eliminate all pollutants. (7) Adopt an agricultural practices act which includes sediment and erosion control, licensing and control over application of agricultural chemicals to include pesticides and artifical fertilizers, and creation of an agricultural practices control board. (8) Promote the cooperation or integration of the various state agencies involved in water quantity and quality issues.

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[1] Their approach, which is briefly summarized here, is presented in Radosevich and Skogerboe, "An Influent Control Approach to Irrigation Return Flow Quality Management" in Law and Skogerboe, Proceedings, pp. 423-434 as well as in Radosevich and Skogerboe, Achieving Irrigation Return Flow Quality Control, section 8.

While all eight of these suggestions merit careful consideration, the highest returns may lie with step (3), introducing incentives to use water more efficiently. As noted in section 5, where water is expensive, it is profitable for farmers to adopt a wide variety of water conservation practices. And, as noted in the present section, these water conserving irrigation practices generally are the most effective means for reducing runoff, the source of most of the erosion and water quality contamination associated with irrigated farming. In most cases the necessary incentives can be provided by eliminating the institutional obstacles preventing water from being valued in accordance with its scarcity value (see section 4). In a few cases the social costs of a farmer's water use might remain well above the private costs even after introduction of water markets. In such cases it might be desirable to supplement the market mechanism with taxes designed to equate private and social costs of water use. Or, if taxes are politically unacceptable, more direct measures could be used to guide farmer behavior towards socially more desirable farming practices. Although water markets would not eliminate the environmental problems associated with irrigation, those remaining after the obstacles to water transfers are eliminated would be less extensive than at present and, thus, more amenable to correction through specifically targeted state programs. And in addition to going a long way towards curbing the negative environmental impacts of irrigation, more active water markets would encourage a more efficient allocation of the West's increasingly valuable water resources.

SECTION 7

SUMMARY AND CONCLUSIONS

Previous sections have examined the factors most likely to influence the future of irrigated agriculture in the West. Among the factors examined are past trends in irrigated acreage, availability of and emerging demands for water, water institutions, impacts of rising energy costs and pumping depths on water costs and profitability, emerging technologies, and environmental problems associated with irrigation. The principal objectives of this section are to consider the implications of these various factors on the future of western irrigation and the overall policy implications of the analysis. Preliminary to this synthesis, the factors affecting the future role of irrigation are briefly reviewed and the irrigated acreage projections of several major government studies are presented and discussed. Then projections as to both the quantitative and qualitative changes likely to occur in Western irrigation over the next several decades are made based on the analysis of this study. Some concluding comments on the broad environmental implications of these trends and the policy implications of the changing water situation are presented.

REVIEW OF THE FACTORS AFFECTING THE FUTURE OF IRRIGATION

Past Trends

The addition of about 25 million irrigated acres in the West was an important factor in the ability of American farmers to increase crop production by 70 percent from 1950 to 1977 without any net increase in total harvested acreage. A very rough estimate of the impact of irrigation of four principal crops on agricultural land use suggests that the higher average yields obtained on these irrigated lands reduced the harvested land required to produce the 1977 national output of corn, sorghum, wheat, and cotton by 7 million acres. Furthermore, by making high productivity farming possible in arid areas, irrigation has expanded the acreage suitable for agriculture by about 10 to 13 million acres.

Analysis of four principal crops--corn, sorghum, wheat, and cotton--suggests that, while western irrigation had a significant impact, it was not the principal factor underlying the impressive increases in national average crop yields from 1950 to 1977. The combination of the improved yields on irrigated farms and the increase in the relative acreage devoted to irrigation accounted for 13 percent of the national rise in corn yields, 16 percent for sorghum, 7 percent for wheat, and 44 percent for cotton. Irrigation's contribution to production increases was even greater; 28 percent of the national increase in corn production over this period was on irrigated lands, 20 percent for sorghum, 12 percent for wheat, and 175 percent for cotton.

Examination of changes in the rate and location of the growth of western irrigated acreage indicates two broad trends which are likely to continue in the future. The rate of growth of irrigated acreage has declined steadily over the last three decades, and the locus of the growth has moved from the south to the north. From 1945 to 1954, 79 percent of the growth of irrigated acreage was in a southern belt extending from Texas and Oklahoma to California. In subsequent decades, this region contributed 31 percent and then only 1 percent of the overall growth of western irrigation. Analysis of the water supply and demand conditions and the adverse impacts of rising energy prices suggest that irrigated acreage has probably started or will soon start to decline in this southern belt. In contrast the central and northern High Plains contribution to the expansion of western irrigation rose from about 10 percent from 1945 to 1954 to over 90 percent from 1964 to 1974. Since Nebraska is one of the few western states for which significant further expansion of irrigated acreage appears likely, this percentage is likely to rise even further.

Water Supplies

Total surface water withdrawals for irrigation have fluctuated around a level trend since the mid-1950s, and the combined impact of several factors suggests this situation may continue for several more decades. First of all, total water requirements exceed average year streamflows within the West's principal irrigated areas and there is little water available for expansion in most of the other areas. Where there is water for expansion, the increases will go primarily to nonagricultural users who can afford to pay higher water costs. The comparative stability of surface water use for irrigation in the face of increasing water scarcity reflects in part the insulation of most surface water costs from both market considerations and rising energy costs. Undoubtedly, there will be transfers of water from agricultural to other uses, particularly within the water-scarce areas, as farmers are presented with increasing opportunities to sell their water rights. However, since large percentage increases in other water uses can be accommodated with small changes in irrigation water use, at least over the next several decades, the impacts of such transfers on irrigation will be gradual and relatively minor from the perspective of the entire West. Moreover, transfers of water rights from irrigation to other uses in the water-scarce areas are likely to be offset in part by modest increases in irrigation within the regions where surface water is still available for appropriation. Federal irrigation projects, which are encountering increasing resistance to their high investment costs and the high opportunity costs of diverting more scarce water to irrigation, will not make any further significant contribution to the expansion of western irrigation.

For several decades the growth of western irrigation has been based on groundwater withdrawals which rose threefold between 1950 and 1975. Currently groundwater withdrawals, which account for about 39 percent of all western irrigation water, result in the mining of more than 22 million acre-feet per year from western aquifers. Even though groundwater stocks are still large in relation to current use and mining is not a threat to exhaust physically the water stored in any of the water resource regions or subregions in the foreseeable future, the combination of the overdrafts and rising energy costs threaten the economic supply of water for many irrigators. In some regions, especially the High Plains, the combination of increasing pumping depths, declining well yields, and rising energy costs already has started to curtail pumping and irrigated acreage. In the absence of sharp increases in real crop prices, future expansion likely will be limited to areas with relatively low pumping depths or access to energy supplies under relatively favorable terms. But combining one or both of these conditions with favorable growing conditions will become increasingly rare.

The water available for irrigation is not likely to be augmented significantly in the next several decades through development of unconventional sources of supply. Although some forms of weather modification, particularly winter cloud seeding, appear technologically and economically promising, institutional obstacles are apt to inhibit its widespread adoption. Cost factors associated in part with their high energy intensity suggest that water importation and desalinization of sea water will not be profitable for use in irrigation. And a combination of cost, technical, and institutional uncertainties make icebergs an unlikely source of western water for the foreseeable future.

Institutional Factors

Western water law and management institutions were developed when water was plentiful in relation to demand. Important objectives of early water law and policy were to give investors clear and unambiguous title to water rights, to encourage the development of water resources, and to minimize uncertainty and conflict among users.

Today, the West faces a situation where water is scarce in relation to demand and the costs of developing new supplies are high in relation to its value in irrigation. Urban, industrial, recreational, and wildlife needs for fresh water are becoming increasingly competitive with irrigation. Yet, there has not been a corresponding adjustment in the laws and institutions that control and manage the resource. All too often the laws and institutions governing water use limit rather than facilitate the transfer of water to higher-valued uses and stifle rather than encourage conservation measures. Such deficiencies are common with most state water institutions, but they are especially severe in the case of federal projects which provide irrigators enormous subsidies but little to no opportunity or incentive to benefit from conservation.

Groundwater users do not have the security of long-term access to low cost water enjoyed by the owners of senior surface water rights. Groundwater supplies often are depletable resources threatened by the addition of new wells, and the costs of pumping are closely linked to energy costs. Individually pumpers have improved the efficiency of their water use; collectively they have sought government help in limiting depletion and curbing water cost increases. Many states have enacted or are considering legislation to limit pumping in order to extend the life of the aquifers. In terms of achieving a long-term efficient use of the resource, one problem with the current groundwater situation is that farmers' costs do not include the loss to neighboring farmers and future users of depleting an aquifer. Theoretically, taxes on pumping could internalize these costs, but, practically, it would be difficult to approximate the ideal level for such a tax, and any tax would be strongly resisted by pumpers.

Economic Factors

In general, groundwater irrigators pay the most for their water and are the most susceptible to further cost increases stemming from both rising energy costs and declining water levels. Groundwater costs vary widely depending on the pumping depth and the type and cost of the fuel. For a typical farmer pumping from 200 feet with electricity, water at the wellhead costs about \$24/acre-foot; distributing this water through a center pivot system adds another \$20 to \$30/acre-foot to irrigation costs (assuming 1980 energy prices and deflating all costs to 1977 constant dollars). A doubling of electricity prices would add another \$32 to the costs of irrigation if no adjustments were made to the higher energy costs. Such cost levels would make it difficult to irrigate profitably grains, cotton, and many other crops in the absence of significant increases in crop prices. Farmers confronted with even higher pumping depths and declining aquifers will be even harder pressed to compete. Unless crop price increases compensate for rising water costs, many farmers will be forced to reduce or terminate their irrigation or radically alter their irrigation techniques over the next several decades. An increase in corn prices of roughly 25 percent would be required to offset the cost increases resulting from a doubling of electricity prices.[1]

Surface water costs also vary widely depending on the distance and height the water must be transported to arrive at the farm, the availability of subsidies, and the need for onfarm pumping to get it to the field. Surface water costs, however, tend to be considerably lower than and not as subject to change as groundwater costs. Farmers with senior rights to neighboring surface waters which can be distributed through gravity have the lowest costs and are the least susceptible to future changes. For these fortunate farmers, water is virtually a free resource, and it is probably treated as such unless the farmer has an opportunity to sell or put to alternative uses any water saving. Another fortunate group of irrigators comprises the farmers receiving water from federal water projects. This highly subsidized water is used on nearly 20 percent of the West's irrigated acreage.

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[1] For a farmer producing 105 bushels per acre, receiving $2.70/bushel, pumping 2.5 acre-feet/acre a height of 200 feet, and using a center pivot system, a 28.5 percent increase in corn prices would be required to compensate for a doubling of electricity prices (based on assumptions in tables 5-2 and 5-8).

The opportunities for expanding irrigation with low-cost surface water are virtually nonexistent within the West's principal irrigated areas and very limited in other areas of the West. For the past several decades groundwater has been the basis of changes in western irrigation and it is likely to remain so for the foreseeable future. The direction of future change will depend in large part on the ability of these farmers to adapt to rising water and energy costs.

Total water costs, of course, depend both on the unit cost of water and on the quantity of water applied. Farmers in arid zones who depend on irrigation to supply virtually all the crop water requirements are more affected by a rise in water costs than are those who rely on irrigation as a supplement to precipitation during the growing season. Most irrigators, however, have a wide range of opportunities for responding to high energy and water costs short of abandoning irrigation. Measures such as improving pump efficiency, tailwater re-use systems, and irrigation scheduling already are profitable under a variety of conditions. Future innovations undoubtedly will provide further opportunities for increasing the yields per unit of irrigation water and reducing the cost of water. But since technological developments will not be limited to irrigated agriculture alone, they are not likely to alter the adverse impacts rising energy costs and water scarcity are having on the profitability of irrigated relative to dryland farming. On the other hand, if real crop prices rise as some analysts predict, irrigators with their higher than average yields will tend to benefit more than dryland farmers.

Environmental Factors

There are a variety of environmental problems associated with irrigation but the only ones likely to have any significant effect on the role of irrigation are groundwater depletion, low streamflows, and salinity.. As noted in the discussion of water supplies, current levels of surface and groundwater use limit the opportunities for increasing water withdrawals to the northern areas and eventually will require a reduction in withdrawals where the aquifers are being mined, which is primarily in the southern areas.

Current water requirements defined to include instream uses exceed average streamflows in the most favorable areas for irrigation. If irrigation water use were curtailed to the levels required "to ensure maintenance of streamflow for optimum fish and wildlife habitat and other environmental values," analysis undertaken by the U.S. Department of Agriculture as part of the Agricultural Resource Assessment System suggests irrigated acreage would have to be reduced by 22 percent in comparison to the moderate export run for 1985 without environmental restrictions.[1]

An estimated 25 to 35 percent of the West's irrigated lands have salinity problems. But the lands where salinity is likely to significantly curtail production comprise a much smaller percentage. The productivity of several million acres, primarily in the lower Colorado River Basin and California's San Joaquin Valley, are threatened by high salt levels. The annual damages to agricultural plus municipal and industrial users of the salt laden waters already probably exceed $100 million, and they undoubtedly will rise unless preventive measures are taken. Improved basin-wide and onfarm water management have great potential for reducing salinity levels and mitigating the damages from high salt levels. However, institutional obstacles to adopting improved basin-wide management schemes and the high costs of some of the structural measures that might achieve the same result suggest an increasing number of farmers will be confronted with serious salt problems. Nevertheless, although the impacts will be serious within the affected areas, the overall impact on the productive potential of western irrigation is not likely to exceed 2 to 3 percent over the next several decades.

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[1] U.S. Department of Agriculture, Agricultural Resource Assessment System: Alternative Future Analysis, Vol. II, 1978, pp. 68-89.

Another environmental problem that could affect the growth of irrigation over the next several decades is groundwater pollution from the infiltration of agricultural chemicals. The most likely area to experience a significant expansion of irrigation is the Nebraska Sandhills, where agricultural chemicals, especially nitrogen, are readily leached into the groundwater. Good onfarm water management can keep nitrate levels within tolerable levels, but failure to adopt such practices could lead to state intervention to enforce better management practices, possibly limiting the growth of irrigation in the area.

PROJECTIONS OF IRRIGATED ACREAGE

National-Interregional Agricultural Projections System

One of the two major models of U.S. agricultural production providing medium and long-term projections of irrigation is the National-Interregional Agricultural Projections (NIRAP) system developed by the Economics and Statistics Service of the U.S. Department of Agriculture (USDA). NIRAP is a simulation model capable of providing considerable subsector and regional detail of the agricultural sector. The model's irrigation figures start from census of agriculture data and rely largely on trends, adjusted to reflect the comments of local experts, to project future levels.

Under the baseline (Series II) assumptions, NIRAP projects irrigated acreage in the seventeen western states at 39.7 million in 1985, 41.3 million in 1990, and 44.5 million in 2000.[1] All these figures are well below the 50.2 million acres the NRI estimates were irrigated as of 1977. The low NIRAP projections do not stem from a conclusion that irrigated acreage will decline over the next two decades. Rather the low projections largely reflect the fact that the model uncritically accepts the census data as a starting point. This feature together with the partial reliance on trends to determine future changes in irrigation suggest the NIRAP system has little value as an indicator of future irrigated acreage.

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[1] The Series II (moderate increase) assumptions include population levels of 242 million by 1990 and 260 million by 2000, a 3 percent per annum increase in GNP, a 2.2 percent per annum increase in disposable income, and a moderate growth of agricultural exports. The NIRAP results were provided by the Economics and Statistics Service of USDA.

The Iowa State Model

The other major model which projects irrigated acreage and production is a linear programming model developed at Iowa State's Center for Agricultural and Rural Development (CARD) under the leadership of Earl Heady. The objective function of this model is to derive the least-cost means of producing exogenously determined demand levels subject to the restraints built into the model as to the availability of land, water, and other factors. The model divides the nation into 105 producing areas, each of which has restraints for land availability (broken down into nine dry and irrigated land classes), the level of production of eight crops, and a minimum irrigated acreage.[1] The Iowa State model and its variations have been used for several major studies designed to assess long-term agricultural developments. Among these studies are the Agricultural Resource Assessment System (ARAS) and the work mandated by the Soil and Water Resources Conservation Act (Public Law 95-192) which are considered briefly below.

The USDA was assigned the task of developing the agricultural and related water use projections for the Second National Water Assessment. In response USDA linked up with Iowa State's CARD to develop the Agricultural Resource Assessment System. The Iowa State linear programming model, which was substantially revised for the purpose, was used for the ARAS projections. Alternative scenarios involving variations in factors such as the demand for U.S. agricultural products, land and water conservation standards, and energy development were examined. Among the outputs from the model are projections of irrigated acreage.

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[1] The model is described in Anton D. Meister and Kenneth J. Nicol, _A Documentation of the National Water Assessment Model of Regional Agricultural Production, Land and Water Use, and Environmental Interaction_, Iowa State University, CARD Miscellaneous Report, December 1975.

The ARAS projections of irrigated acreage under the "modified central choice" (which is considered the most likely situation), the high demand for U.S. agricultural products, as well as all other scenarios considered are well below the 1977 levels estimated by the National Resources Inventory. The modified central choice scenario projects western irrigation at 38.4 million acres in 1985 and 40.0 million acres in 2000. The high export scenario increases the acreages by only 0.7 million acres in 1985 and 0.3 million in 2000. A land and water conservation scenario which constrains cropping patterns and conservation practices to maintain long-run productivity actually reduces irrigated acreage to 39.2 million in 2000.[1]

Since the Iowa State model provides a least-cost solution, one interpretation of the ARAS results is that any other outcome would entail higher production costs. Within the assumptions of the model, this interpretation, of course, is correct. But since the projected irrigation levels are so low in comparison to actual levels, the results raise some question about how irrigation is treated in the model. The economics of irrigating differ considerably depending on the availability of the infrastructure required to get water to the field. For example, if the well and canals are already in place, their costs are incurred whether or not the farmer actually irrigates. Thus, the initial level of irrigation and the availability of the required infrastructure are likely to be key determinants of the level of irrigation deemed profitable by the model. The ARAS base year levels are from the 1967 CNI updated to 1973 for irrigation; allowance is also made for WPRS projects expected to be in place as of 1985 and 2000. The comparatively high level of irrigation in the 1977 NRI raises questions as to whether or not these assumptions accurately reflect the economic situations facing farmers. On the other hand, the analysis of water institutions, water supply conditions, and economic factors presented in earlier sections of this study suggest that most irrigators are not paying the full costs of water. Thus, the conclusion that a more socially efficient production would have a lot fewer acres under irrigation than are actually irrigated may well be correct. Nevertheless, as it is currently used, the Iowa State model is a poor vehicle for projecting irrigated acreage. Indeed, although the ARAS system was undertaken to provide projections for the Second National Water Assessment, the Water Resources Council (WRC) concluded that the model was not capable of describing accurately the agricultural resource situation; alternative projections (presented below) were made for the Assessment.

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[1] U.S. Department of Agriculture, Agricultural Resource Assessment System; Vol. I, Benchmark Analysis and Modified Central Case and Appendix A and Vol. II, Alternative Futures Analysis and Appendix A, April 1978.

More recently the Iowa State Model has been used by the USDA in assessing the nation's long-term soil and water needs as mandated by the Soil and Water Resources Conservation Act (RCA). The land base data used in the model were updated for the RCA process to incorporate the results of the 1977 NRI. Yet, the RCA projections of irrigated acreage still remain well below the NRI's estimated level for 1977. Irrigation as of 2000 is projected at 33.9 million acres for the medium demand case and at 40.1 million acres for the high demand case.[1]

The Iowa State model also was used to complement the Resources for the Future (RFF) study of the resource and environmental impacts of agricultural growth. The two model runs done for the RFF study assume demand for U.S. farm output is high in comparison to the RCA moderate scenario. The focus of the model runs for RFF was to examine the adoption of conservation tillage practices and erosion levels under alternative assumptions. Irrigated acreage for 2010 was projected at 45.6 million under the scenario with no restrictions on the model's allocation of tillage practices and at 43.7 million when the land placed in conservation tillage was restricted.

Second National Water Assessment

As noted above, the ARAS was initiated to provide estimates of irrigated acreage and associated water use for the Second National Water Assessment, but the results of this analysis were not incorporated into the Assessment. Instead, two separate estimates of irrigated acreage are presented in the Assessment--the National Futures (NF) estimate which was developed by group consensus of representatives from the federal agencies involved in the Assessment and the State and Regional Futures (SRF) developed by the committees established by the WRC in each region. These committees were composed of local river basin, U.S. Geological Survey, and Soil Conservation Service officials and others.

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[1] The assumptions of high and medium demand cases differ by more than the demand levels. Assumptions used in the RCA linear program are described in U.S. Department of Agriculture, 1980 Appraisal: Review Draft Part II, chapter 2, 1980. RCA data were provided by David Post, U.S. Department of Agriculture, Soil Conservation Service.

Both the 1975 base year levels and the 1985 and 2000 irrigation projections of the two groups differ significantly. Not only are the SRF base year estimates higher than the NF (46.3 versus 40.5 million acres), the rates of expansion of the SRF projections also are much higher. The NF projects a 7 percent increase in irrigated acreage by 1985 to 43.4 million acres and a further increase of only 1.2 million acres by 2000. In comparison, the SRF projects a 16 percent rise to 53.6 million acres in 1985 and an additional 14 percent rise to 61.0 million acres by 2000. By the turn of the century the SRF projections show 37 percent more acres irrigated than do the NF projections. Unfortunately, the Assessment does not provide justification for either set of irrigation projections.

Projections from this Study

Over the next several decades changes in total irrigated acreage will depend in large part on what happens to agricultural prices. Indeed, the relation between crop price levels and the expansion of irrigation will be much stronger than in the past. Past expansion was primarily a function of technological developments, water projects, and a learning process as farmers followed what their more progressive neighbors had proven successful. Future expansion will be influenced by very different cost and resource conditions which make past trends of limited use for making projections and the profitability of irrigated relative to dryland farming in many areas dependent on higher crop prices.

Although irrigation in many areas of the West is constrained by physical and institutional limits on developing new water supplies, there are additional lands with access to water for irrigation. Within these areas, the important constraints on irrigation are economic. Significant increases in product prices would offset the negative impacts of high energy prices and increasing pumping depths; the development of new irrigated lands would be stimulated, and the decline in irrigated farming in areas with significant groundwater mining would be slowed.

Table 7-1 summarizes what should be viewed as very rough projections of irrigated acreage by farm production region during the decade from 2000 to 2010 under alternative assumptions of no change and a 25 percent increase in real crop prices.[1] These projections are impressionistic estimates drawing on the analysis of recent trends, water supplies, and institutional, economic, and environmental factors examined in sections 2 to 6 of this study.

Even in the absence of any significant change in crop prices, some net expansion of western irrigation seems likely. Most of the expansion will be in the Northern Plains states, and more specifically within the Nebraska Sandhills. This area has considerable potential for expansion, and based on recent investments in wells and center pivots, irrigation investment in

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[1] A range of 2000 to 2010 for the projection period is used to indicate the very rough nature of the projections as well as to reflect a suspicion that total irrigated acreage in the West will peak during this decade in the absence of major institutional changes providing the owners of surface water rights with strong incentives to adopt water conservation practices. In 1977 constant dollars, the average prices received by farmers in the United States from 1975 to 1980 was \$2.21/bushel of corn, \$3.01/bushel of wheat, \$3.69/cwt of sorghum, and \$0.56/lb of cotton lint. Inflating these prices by 36 percent would convert them to 1980 prices. These price levels are based on 1980 preliminary prices from U.S. Department of Agriculture, Economics and Statistics Service, Agricultural Outlook, March 1981, p. 27 and 1975 to 1979 prices from U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, Agricultural Prices Annual Summary 1979, June 1980.

Table 7-1. Projections of Irrigated Acreage by Farm Production Region Under Alternative Crop Price Scenarios

(millions of acres)

	1977 NRI Estimates[1]	Projections for 2000 to 2010	
		No Change in real crop prices	25% rise in real crop prices
Northern Plains	10.7	15.0	16.5
Southern Plains	9.0	7.0	8.0
Mountain	17.2	16.5	17.5
Pacific	13.3	15.0	16.0
17 Western States	50.2	53.5	58.0

[1] From table 2-1.

the area is profitable at current price levels. Modest increases in irrigation within the Dakotas is also likely although irrigation will remain relatively unimportant in these states. The increases within the Northern Plains will be partly offset by some reduction in irrigation in the Kansas and Nebraska High Plains.

The impacts of high energy costs and declining groundwater tables will force a significant decline in irrigation by the turn of the century within the High Plains of Texas and Oklahoma. Increases in irrigated acreage within the eastern areas of these states will be modest in comparison to the declines in the western areas. Thus, with no change in crop prices, a 2 million acre decline in irrigation is projected for the Southern Plains.

The Mountain region will experience little net change in irrigated acreage but within this large, heterogeneous area comprising eight states, significant changes in the location of irrigation are likely. The southern areas and eastern Colorado, where current levels of irrigation are dependent on nonrenewable water sources, will experience some decline in irrigated acreage. In the absence of high crop prices, these declines will be offset only in part by some modest increases in irrigation within the rest of the Mountain region.

In the Pacific region a modest overall expansion of irrigation is likely even with no increase in crop prices. A 1974 California water plan by the Department of Water Resources projected their state's irrigation would reach 9.5 to 10.6 million acres by 1990 and 9.8 to 12.1 million by 2020.[1] These levels compare to the NRI's estimate of 8.9 million acres in 1977 and the state's estimate of 9.3 to 9.6 million as of 1980.[2] The increases implied by the higher projections of the plan are improbable in view of the other demands being made on the State's water, the high cost of developing new supplies, groundwater mining in some regions stemming from current water use patterns, the prospective loss of nearly 1 million acre-feet per year of Colorado River water once the Central Arizona Project is completed, and the salinity problems threatening a million acres in San Joaquin Valley.

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[1] The Resources Agency, State of California, The California Water Plan: Outlook in 1974, November 1974 Summary Report, Department of Water Resources Bulletin No. 160-74, pp. 34-35.

[2] Based on Agricultural Commissioner reports for each county and the Resources Agency's land use surveys, Warren Cole estimates there were 9.3 million acres with full irrigation and 0.3 million with low water applications as of 1980. Personal communication February 28, 1980 with Warren Cole, supervising engineer of the California Department of Water Resources.

Indeed, the 1974 water plan did not even consider water as a constraint on expanding irrigation. Correcting for this oversight makes the high projections of the 1974 plan appear much too optimistic. Overall, California's irrigated acreage is not likely to rise significantly above 10 million acres by 2000. While the Pacific Northwest is the area least affected by water shortages, the region's water is becoming increasingly valuable for use in hydropower production and preserving the wildlife and amenities of the area. Furthermore, very inexpensive electricity is no longer available for expanding pumping. Consequently, additions to irrigated acreage in the Northwest over the next several decades are not likely to push the totals for Washington and Oregon much beyond 5 million acres without significant crop price increases.

A 25 percent increase in real farm prices might add another 4.5 million irrigated acres in the West, more than doubling the growth of irrigated acreage over the next two to three decades. Yet, even assuming such a substantial increase in crop prices, irrigation is projected to rise only 15.5 percent over two to three decades. In comparison, western irrigation doubled over the previous twenty-five years and rose 21 percent from 1967 to 1977. The long-term elasticity of irrigation with respect to crop prices implied in the projections of table 7-1 is only about 0.3 (i.e., a 25 percent increase in crop prices increases irrigated acreage by about 8 percent). This low anticipated sensitivity to real price levels is primarily a reflection of two factors--the fact that no foreseeable crop price levels will make irrigation competitive with most municipal and industrial water uses and the importance of institutional and resource factors in determining the level of irrigation. Few areas have the water to support a major expansion of irrigation under any realistic projections of crop prices. Groundwater is often the only water available for expansion but many Western aquifers are already being mined at significant rates. Major expansion of surface water irrigation outside of the areas that have other significant handicaps to high-productivity farming requires institutional changes which will provide irrigators with incentives to conserve water. Conservation would enable the available supplies to be spread over more acres. In the absence of such changes, groundwater will remain the primary water source for new irrigation. While high crop prices will encourage greater pumping, the impacts of increased pumping on total irrigated acreage may be relatively short-lived in view of the nonrenewable nature of much of the groundwater.

QUALITATIVE CHANGES IN WESTERN IRRIGATION

The nature as well as the rate of growth of irrigation will be very different from the past when irrigated farming was stimulated by the availability of inexpensive water and energy. Water withdrawals will be reduced as it becomes more profitable both to make water saving investments and to reduce the water delivered to the plant even if it means some reduction in crop yields. While total irrigated acreage may not peak until the first decade of the next century, total withdrawals for irrigation probably will peak much sooner, perhaps within the next decade. Improved yields to water inputs and shifts to higher-value crops will enable the value of production from irrigated farms to rise even after the quantities of land and water in irrigation have peaked and started to decline. Thus, both water withdrawals and acreage are likely to become increasingly poor indicators of changes in the contribution of irrigated output to national agricultural production.

As is evident from a recent report of an interagency task force group which assessed the potential for improving the efficiency of irrigation water use and management in the United States, most water conservation opportunities actually imply a substitution between water and other inputs such as capital, labor, and improved water and agronomic management. There are, of course, limits on the substitutions which are profitable, and these limits depend importantly on the cost of water. The task force group concluded that in addition to "on going programs, public and private investments of up to five billion dollars should be made over the next three decades to implement needed water conservation measures." These investments could "result in decreasing gross annual diversions by 15 to 20 million acre-feet and making two to five million acre-feet of water available for new uses.[1]

The task force study's conclusions draw on the results of Soil Conservation Service (SCS) field estimates of the measures required to achieve a "reasonable level of irrigation water management" in the seventeen western states. The major need for reducing conveyance losses is lining canals or piping to reduce seepage losses. Further reductions in conveyance losses could be made through consolidation, realignment, or enlargement of canals and control structures. In total an estimated 3.1 million acre-feet of water per year could be saved through off-farm investments of $6.2 billion.

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[1] U.S. Department of Interior, U.S. Department of Agriculture, Environmental Protection Agency, Irrigation Water Use and Management: An Inter-Agency Task Force Report, June 1979, p. ix.

Onfarm water losses can be reduced through lining or piping of field distribution systems, land leveling, water control or measuring structures, automation, tailwater recovery systems, and changing to sprinkler or drip irrigation. The SCS survey concluded that "about one-fourth of the irrigated land in surface systems requires land leveling, over one-third could use tailwater recovery systems to reduce return flows, and about 60 percent should use more effective ways to schedule and apply water to meet the needs of the crops and reduce deep percolation and excessive return flow." In total an estimated investment of $8.4 billion plus an annual cost of $142 million for irrigation water management could reduce onfarm water losses by 4.5 million acre-feet per year.

In addition to the reductions in irrecoverable or incidental water losses, other major changes in water management are implied by these infrastructure investments. For example, the proposed measures would result in a 38.6 million acre-feet reduction in water withdrawals, a 35.3 million acre-feet reduction in return flows, a 4.3 million acre-feet increase in crop water consumption (which helps increase farm output by $500 million per year), and a $109 million reduction in energy requirements.[1]

Future federal water projects likely will focus more on improving water use efficiency and preserving the productivity of existing irrigation rather than continuing the past concentration on developing new supplies. Numerous opportunities for reducing on and off-farm water losses through structural means are noted in the task force study cited above, and major structural solutions for reducing salinity problems in the Colorado River Basin and the San Joaquin Valley are noted in section 6. Even if the economics of such projects are not more favorable, they have political advantages relative to supply-oriented projects. Well organized and powerful environmental interests can be expected to oppose efforts to develop additional western streamflows for use in agriculture, but there is no established opposition to conservation or salinity control projects other than those concerned with the budgetary considerations of any major government project.

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[1] The information and the quotes in this and the preceding two paragraphs are from USDI, USDA, EPA, Irrigation Water Use and Management, pp. 84-85 and tables 14, 15, and 18. California's Department of Water Resources has serious reservations about whether the water savings identified in the task force report actually refer to water that would otherwise be unuseable. Gerald Meral, Deputy Director of the Department of Water Resources, suggests that the analysis for California did not differentiate savings subject to reuse from those that would otherwise be lost to the system. It is conservation of the latter type that can be viewed as an alternative to developing new supplies through construction of reservoirs or interbasin transfer facilities. (Meral's reservations were expressed in a 4 December 1980 letter to the author.)

Nonstructural measures may prove to be even more important than the structural alternatives for improving the returns to water in irrigation. Improved irrigation scheduling, higher-value or less water-using crops, tillage practices designed to conserve soil moisture, and seed varieties offering higher returns to water will become increasingly attractive to farmers confronted with high water costs. Furthermore, the technologies available for responding to high water costs can be expected to expand significantly in the coming decades. For example, California's Department of Water Resources believes there is considerable potential for reducing evaporation from cropped areas and increasing the portion of transportation directed to commercially desirable features of the plant. Three requests for proposals were issued by the Department in the fall of 1980 for (a) preparing a report on cropping pattern changes to conserve water, (b) a study of the relationships between evaporation from soil and water surfaces and plant transpiration to identify means of reducing evaporation from irrigated lands and to evaluate the potential for water conservation savings by such means, and (c) a report on potential for saving water through the use of improved cultivators.[1]

The overall potential for increasing irrigated production through a combination of structural and nonstructural measures without increases in total water use is great. The extent to which this potential is realized depends in large part on the institutions and policies affecting water use. Before turning to the overall policy implications of the analysis, however, the environmental issues are reviewed since alternative policies should be evaluated for their environmental as well as for their production implications.

ENVIRONMENTAL IMPLICATIONS OF ANTICIPATED QUALITATIVE AND QUANTITATIVE CHANGES IN WESTERN IRRIGATION

The changing character of the growth of irrigation is having some beneficial environmental effects. As is noted in section 6, the environmental problems of erosion, sedimentation, and water quality degradation which are associated with irrigation generally diminish as the application efficiency of water increases. Thus, the same investments and irrigation practices that are becoming attractive to irrigators as water costs rise also help reduce the environmental damages caused by over-irrigation.

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[1] Department of Water Resources, The Resources Agency, State of California, requests for proposals Nos. 80 AG-CONS-2, 5, and 8.

Adoption of improved water management practices, however, largely has been limited to farms with expensive water. Although water costs are generally rising, a large segment of surface water users, including many of the biggest environmental offenders, remain insulated from the impacts of increasing water scarcity. Little improvement in the environmental impacts of their farming practices is likely as long as these farmers pay little for their water and nothing for the environmental damages resulting from their use of the water.

Understanding the environmental implications of irrigated agriculture requires looking beyond the impacts associated with the irrigation process itself. Irrigation is both a land-conserving technology and a means of expanding the land that can be used for cropping in arid and semi-arid regions. Since irrigated yields tend to be much higher than the overall average, any change in the number of irrigated acres affects the total number of cropped and pastured acres required to produce a given output. Consequently, an increase in irrigation reduces the pressures on other agricultural land resources, an outcome of increasing importance when the marginal lands that would be brought into production in the absence of irrigation are environmentally fragile. The anticipated reduction in the growth of irrigation suggests that future growth of agricultural output will place greater pressures on the land base.

Several studies suggest the environmental costs of substantially increasing the cropland base would be high. A study of the potential for and costs of converting woodland and pastureland to cropland in the Mississippi Delta region estimates that conversion would increase soil erosion by an average of 8.38 to 14.06 tons/acre depending on the number of acres and the soil groups converted and the crop rotations selected.[1] A similar study of the State of Iowa indicates that converting up to 2.5 million acres to cropland in Iowa would require using larger portions of highly erodable lands with steep slopes.[2] To some extent, these are environmental costs that have been avoided by the growth of western irrigation; assessing policies that will affect the future role of irrigation should take these impacts into account. For example, restricting water withdrawals to ensure streamflow for optimum fish and wildlife habitat (and, thereby decreasing irrigation water use by 22 percent) undoubtedly would hasten the conversion of highly erodable lands to crops. These conversions in turn would have adverse impacts on water quality in the affected areas.

POLICY IMPLICATIONS

The policies, laws, and institutions governing the use of western waters were developed largely during a period when water supplies were abundant relative to demand. An important objective of the 1902 Reclamation Act was to stimulate settlement of the arid West, and the subsidies built into federal irrigation projects undoubtedly encouraged western rural settlement during the first five or six decades of this century. Moreover, by providing assurances of continued access to water, state water laws helped attract investment to the West.

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[1] Robert N. Shulstad, Ralph D. May, and Billy E. Harrington, Jr., "Cropland Conversion Study for the Mississippi Delta Region," University of Arkansas, a report prepared for Resources for the Future, April 30, 1979, pp. 139-142.

[2] Orley M. Amos, Jr., "Supply of Potential Cropland in Iowa," a Ph.D. dissertation, Iowa State University, preliminary draft, February 7, 1979, p. 149.

Farmers have never had to pay for water rights, only for the cost of getting water from its source to the farm. And even these costs often have been subsidized. Charging farmers for only the costs of delivering water to their fields is an economically sound pricing policy under conditions of abundant water. When there is sufficient water in a stream to satisfy all users and no environmental costs are associated with a given use, there are no additional costs to withdrawing surface water. Likewise, as long as groundwater pumping doesn't exceed natural recharge or affect neighboring users, the farmer's pumping costs reflect the social costs of groundwater use. But these conditions no longer prevail in most of the West. Commonly, water requirements exceed streamflows and groundwater use exceeds recharge. Consequently, the water itself has a value which should be reflected in user's costs if water is to be used efficiently.

Water is now a principal constraint on further development, and the subsidies and laws insulating many water users from the increasing value of the resource have become a deterrent rather than a stimulant to development. State laws and policies not only allow an inefficient use of western water, they ensure it by reducing or eliminating the incentives and opportunities for transferring water to higher-value uses.

Improving the efficiency of western water use does not require forcing the owners of water rights to pay for what has been legally given to them. Indeed, any attempt to abrogate these rights would be futile and potentially damaging to the region since it would threaten the entire legal and institutional structure that has brought order to the allocation of western water. A more acceptable alternative for providing incentives to conserve water in areas where it is scarce is to allow and facilitate the sale of water that is not used by the owners of the water rights. Then, even if a farmer does not have to pay for the water, there would be an opportunity cost to putting the water to any particular use. In many western states, the principal changes in existing water laws required to implement water markets would be to classify water sales as a beneficial use and to eliminate provisions making water rights appurtenant to a given piece of land. Of course, farmers must have an opportunity as well as a right to transfer water if a more efficient allocation is to be achieved. Establishing effective water markets will require the creation or transformation of institutions to provide for the transfers of money and water.

Since irrigation is a relatively low-value user, a more market-oriented allocation system is likely to transfer water from irrigation to municipal, industrial, and other uses. However, these negative impacts on irrigation might be more than offset by the added incentive that would be provided to increase the returns to the water used in irrigation. Moreover, since irrigation is such a predominant user of western waters, a small improvement in the efficiency of irrigation might save enough water to satisfy nonagricultural water needs without significantly reducing irrigated acreage. Where irrigated acreage is reduced, market forces would focus the impacts on the lower-value uses such as forage and pasture. A reduction in the environmental damages from irrigation practices would be a further benefit of policies designed to make water costs more nearly reflect the scarcity value of the resource.

If the transition from water abundance to scarcity allows for an efficient use of the resources over time, irrigation will contribute to agricultural production and growth for many more decades. Future potential lies primarily in increasing the returns to water, not in the development of new water supplies. Realization of this potential requires providing incentives to conserve water and encourage the development of more effective ways for farmers to respond to higher water and energy costs and salinity levels. The social returns to agricultural research have been very high in the past, and the benefits from research to develop improved irrigation practices, new crops and seed varieties requiring less water, improved understanding of the transpiration of plants, and a host of other promising areas for increasing the options for irrigated farming are likely to be very high in the future. These research efforts, which represent the real hope for the long-term contribution of western irrigation to agricultural production, should be encouraged. Nevertheless, innovations will be adopted in a timely way only if the institutions provide the correct incentives regarding use of the region's scarce resources.

Western irrigation is not likely to make the contribution to agricultural growth that it did when water was abundant and cheap even if the relevant research is encouraged and institutional reforms are made. The inevitable adjustments to declining groundwater supplies will not be pleasant. Nevertheless, the socially most expensive response would be to provide subsidies to either enable farmers to pump to greater depths or to import water. An area where agriculture depends on declining groundwater supplies inevitably will become a higher-cost irrigated producer. Spreading the cost increases among the general public clearly helps farmers in the affected region. But it also ensures higher overall production costs due to inefficient use of society's resources. The serious problems will emerge if we attempt to keep water cheap when it is not. Such efforts will ensure its inefficient use and push the social costs of irrigated production to levels well above those of the dryland alternatives,[1] thereby further limiting the long-term role of irrigation.

Although the underlying resource conditions as well as the national interests in the use of western water have changed dramatically within the last several decades, there has not been a corresponding adjustment in the laws and institutions that control and manage the resource. There is need to identify and develop strategies that will overcome opposition to reform of water development, allocation, and pricing policies and practices. In particular, the equity implications of alternative reforms and the possible measures for compensating those whose livelihood is adversely affected by such reforms need to be analyzed and taken into account in policy formulations. The political task of bringing about real reform might be easier if it could build upon a better and more widespread understanding of the short- and long-term implications of policy alternatives and the role of western irrigation in meeting future food and fiber needs.

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[1] Even now society may be paying more for farm output produced on its irrigated lands. Certainly, irrigated production would not be as great as it is if farmers paid the full cost of getting water to their farms. Moreover, as noted earlier, results of the national agricultural model developed at Iowa State University suggest that our nation's agricultural output could be produced at lower cost with fewer irrigated acres.

APPENDIX

IRRIGATION DATA PROBLEMS

Efforts to describe the past or present role of irrigation in U.S. agriculture face a fundamental problem--there is considerable uncertainty as to how many acres are currently irrigated or have been irrigated in the past. The uncertainty as to irrigated acreage is evident from the alternative estimates presented in table A-1. For example, the Second National Water Assessment offers alternative estimates of 45.3 and 51.9 million acres irrigated in 1975 in the United States. But even this range is not sufficiently wide to encompass alternative estimates for 1975 or neighboring years. If the 41.2 million acre estimate of the 1974 Agricultural Census were adjusted for likely expansion between 1974 and 1975, it would still fall below this range.[1] The

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[1] Preliminary data of the 1978 Census of Agriculture recently have been released which show the United States with 50.7 million irrigated acres in 1978. This figure implies an increase of 9.5 million acres over just four years, a very significant and unprecedented rise. The Bureau of the Census, however, suggests that a comparison of the 1978 with the 1974 and 1969 agricultural censuses overstates actual growth of irrigation. In an open letter dated December 12, 1980, Arnold L. Bollenbacher, Chief, Agriculture Division, Bureau of the Census, states "Because of improvements in coverage for the 1978 census, comparisons with the previous two censuses taken by mail (1969 and 1974) must be approached with caution so that improved counts are not misinterpreted as dramatic changes occurring between censuses..."

The first draft of this study was completed before the 1978 census data were available. Indeed, the detailed state and county level data still are not out for most states. A major additional effort and significant delay would be required to fully analyze and incorporate the 1978 agricultural census into this study. But neither the effort nor the delay seem warranted. The preliminary data and accompanying statements from the Bureau of the Census (see, for example, Bollenbacher's statement in the preceding paragraph) support a major conclusion of this appendix--that the 1969 and 1974 agricultural censuses understate the level of irrigated acreage. While the 1978 irrigation census estimates appear to be signficantly improved over the previous two, underenumeration still appears likely. Although efforts were made in 1978 to include a higher percentage of actual farms in the census, the estimates still depend on responses from farmers, some of whom apparently believe it is in their interest to underreport irrigated acreage. Thus, the 1977 National Resources Inventory still is used in this study as the principal source of recent irrigation levels. Although the analysis has not been redone, references to the irrigation estimates of the 1978 census of agriculture have been added in several instances to this appendix.

Table A-1. Alternative Estimates of Irrigated Acreage, Various Years
(millions of acres)

			17 Western States	U.S. Total
Census of Agriculture		1964	33.2	37.1
First National Water Assessment		1965	38.8[a]	42.1
USGS		1965	39.5	44.0
Conservation Needs Inventory		1967	41.5	47.6
Census of Agriculture		1969	34.8	39.1
USGS		1970	43.7	50.0
Census of Agriculture		1974	36.6	41.2
Irrigation Journal		1974	47.0	53.3
Second National Water Assessment	NF[b]	1975	40.6[a]	45.3
	SRF[c]	1975	46.2[a]	51.9
USGS		1975	47.3	54.0
Irrigation Journal		1975	47.6	54.0
National Resources Inventory		1977	50.2	60.7
Irrigation Journal		1977	49.9	58.5
Irrigation Journal		1978	51.3	60.7
Census of Agriculture (preliminary)		1978	43.4	50.7

[a] Regional estimates in the National Water Assessments are for water resource regions which do not correspond to state boundaries. These figures include regions 9-18.

[b] NF: National Future--Estimates of present and future conditions as obtained primarily by participating federal agencies.

[c] SRF: State/Regional Future--Estimates of present and future conditions provided primarily by participating River Basin Commissions, state agencies, and other sponsors.

Sources: next page.

Census data:

1964 and 1969: U.S. Department of Commerce, 1969 Census of Agriculture, Volume IV, Irrigation, July 1973, table 1, p. 2.

1974: U.S. Department of Commerce, 1974 Census of Agriculture, Volume 1, Part 51, United States: Summary and State Data, December 1977, p. II-5.

1978: preliminary data released by the Bureau of the Census, U.S. Department of Commerce, undated.

National Assessment data:

1965: U.S. Water Resources Council, The Nation's Water Resources, The First National Assessment of the Water Resources Council, Washington, D.C., 1968, p. 4-4-1.

1975: U.S. Water Resources Council, The Nation's Water Resources 1975-2000: Second National Water Assessment, Volume 3: Appendix 1 (Dec. 1978), p. 59.

USGA data:

1965: U.S. Department of Interior, Geological Survey Circular 556, prepared by C. Richard Murray, Estimated Use of Water in the United States, 1965, 1968, table 11.

1970: U.S. Department of Interior, Geological Survey Circular 676, prepared by C. Richard Murray and E. Bodette Reeves, Estimated Use of Water in the United States in 1970, 1972, table 7.

1975: U.S. Department of Interior, Geological Survey Circular 765, prepared by C. Richard Murray and E. Bodette Reeves, Estimated Use of Water in the United States in 1975, 1977, table 7.

Conservation Needs Inventory:

U.S. Department of Agriculture, Soil Conservation Service, Basic Statistics--National Inventory of Soil and Water Conservation Needs, 1967, Statistical Bulletin No. 461, January 1971, table 3c and the a and c state tables.

Irrigation Journal data:

The 1974, 1975, 1977, and 1978 IJ data from Irrigation Journal, Volume 28, No. 6, Survey/December 1978, pp. 46A to 46H.

National Resources Inventory:

U.S. Department of Agriculture, Soil Conservation Services, "Basic Statistics--1977 National Resources Inventory (NRI)," Revised February 1980, in mimeograph.

1975 national estimates of the U.S. Geological Survey (USGS) and the *Irrigation Journal* (IJ) of about 54 million irrigated acres exceed the range of the Second Assessment. Yet both of these estimates are lower than the 60.7 million acre estimate of the 1977 National Resources Inventory (NRI), even allowing for expansion from 1975 to 1977.

The seventeen western states account for 83 to 89 percent of the nation's irrigated land (depending on the data source) and for much of the uncertainty as to how many acres are irrigated. For example, the 1974 Agricultural Census shows only 36.6 million irrigated acres in the West, a figure which is more than 10 million acres below both the 1974 IJ and the 1975 USGS estimates. The differences between the 1977 NRI figure of 50.2 million acres and the 1974 census estimate cannot be explained by the post-1974 expansion of western irrigation.[1]

Variations in what is included as irrigated land is one possible explanation for the data differences. Indeed, the reporting of an interagency task force formed to study irrigation efficiency, concludes "Differences occur because definitions of irrigated lands are not uniform among the different agencies."[2] Differences in definitions that might contribute to variations in irrigated acreage estimates include treatment of land which is normally irrigated but not irrigated that year, land taken out of irrigation for urban development, land which is occasionally wild flooded, and land that is double-cropped under irrigation.

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[1] Preliminary 1978 census data show 43.4 million acres irrigated in the West. However, the qualifications in the prior footnote regarding the use of 1974 and 1978 census data to describe actual changes in irrigation over this period apply to the western as well as to the national data.

[2] U.S. Department of Interior, Department of Agriculture, and Environmental Protection Agency, *Irrigation Water Use and Management, An Interagency Task Force Report* (June 1979) p. 12.

The census estimates, which are generally the lowest, count as irrigated any agricultural land receiving water through artificial means in the census year. Double-cropped land is counted only once and land which is normally irrigated but not irrigated in the census year is not counted.[1]

The 1967 CNI and 1977 NRI define irrigated land as "land on which irrigation water is applied by an adapted irrigation method on a recurring basis as an integral part of crop production."[2] In the 1977 survey, land was counted as irrigated if (a) the enumerator observed evidence that the land had been irrigated that year or (b) the farmer indicated the land had been irrigated at least two of the last four years.

For the First National Assessment, irrigated land was "defined as land developed for irrigation which regularly receives water for the production of agricultural products." This "includes lands which are temporarily idle for water supply or other reasons but does not include lands which do not regularly produce agricultural products."[3] In the Second Assessment alternative estimates of 1975 irrigation are given because of the uncertainty as to the magnitude of irrigation, not because of different definitions. For both sets of estimates irrigated farmland is defined as "pasture and cropland to which water can be expected to be applied."[1] The USGS and IJ rely on local experts for their estimates and do not define irrigated land.

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[1] Total irrigated land in the census includes harvested cropland irrigated, cropland pasture irrigated, pasture (other than cropland pasture) irrigated, and other cropland irrigated. Other cropland includes cropland in cover crops, legumes, and soil-improvement grasses, not harvested and not pastured; cropland on which all crops failed; cropland in cultivated summer fallow; and cropland idle.

[2] U.S. Department of Agriculture, Basic Statistics--National Inventory of Soil and Water Conservation Needs, 1967, Statistical Bulletin no. 461, January 1971, p. 209. Ray Dideriksen, Director, Land Inventory and Monitoring, Soil Conservation Service, indicated that the 1977 NRI irrigation data are based on the same definition.

[3] U.S. Water Resources Council, The Nation's Water Resources, the First National Assessment of the Water Resources Council, Washington, D.C., 1968, p. 4-4-1. This document states that the Assessment was "hampered by inconsistent data on irrigated land."

The different definitions do provide reason for expecting the census estimates to be lower than the alternatives since land that is regularly irrigated but not irrigated in the census year is not listed as irrigated by the census. While the impact of the various definitions on the estimates of irrigated acreage cannot be quantified, the following analysis suggests that the major reason for the wide variations in irrigation estimates is that, with a single exception, the sources of national irrigation estimates either (a) depend on the responses of farmers who may not reply or may believe it is in their interest to misstate the extent of their irrigation, or (b) rely on reports of many individuals or organizations which are asked to estimate a state's irrigation in the absence of clear guidelines or reliable primary data. In the first case, the data are systematically biased in all regions; in the second case, the magnitude and sometimes even the direction of any errors are unknown and differ among states. The only sources of irrigated acreage data which avoid both these shortcomings are the 1967 Conservation Needs Inventory (CNI) and the 1977 National Resources Inventory (NRI).

PRIMARY IRRIGATION DATA

The only primary sources of irrigation data which apply standardized data gathering and estimating techniques to all states are the agricultural censuses (taken about every five years), the decennial irrigation survey by the Bureau of Census (done in recent years after every other agricultural census), the 1967 CNI, and the 1977 NRI.[1]

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[1] U.S. Water Resources Council, The Nation's Water Resources 1974-2000: Second National Water Assessment, vol. 3, Analytical Data Summary, p. 72.

More limited efforts to obtain primary data for estimating irrigation have been undertaken in some states. Each of the seventeen western states has an agreement with the Statistical Reporting Service of the USDA to provide crop and livestock production estimates. Federal appropriations cover the collection and publication of these data on a state and national level only, but make no provision for distinguishing between irrigated and dryland production. Depending on the interests of and the funds contributed by a particular state, more detailed data such as irrigated production and acreage may be collected. Most of the western State Crop and Livestock Reporting Services provide some data on the acreage and yields of principal crops under irrigation, but only a few provide data on total land irrigated in their states.[2] Variations in the detail, coverage, and reliability of the irrigation data provided by the states limit their usefulness in describing the overall role of irrigation in the West. In some cases, however, state data can provide a check on the reasonableness of alternative sources.

The most detailed and widely cited data on irrigated agriculture are those of the agricultural censuses, which include county-level irrigation figures by crop for every state. One might expect the census data to be the most accurate since they are supposed to be based on a survey of all farms. Unfortunately, this expectation is not fulfilled. There seems to be widespread agreement among those familiar with irrigation data that the 1974 agricultural census grossly understates the level of irrigated acreage in the United States. Indeed, upon releasing the preliminary 1978 census data, the Bureau of the Census itself noted that irrigated acreage was underreported in both the 1974 and 1969 censuses. This conclusion is supported by a comparison of census and other sources of irrigation data as well as by conversations with knowledgeable officials in many of the major irrigation states.[1] The failure to achieve full farm coverage is the explanation the Bureau of the Census offers for the underenumeration. But another important reason for the underenumeration may be that some farmers believe it is in their interest to understate the level of irrigation. The accuracy of a mail response system depends on individual responses which are bound to be inaccurate if farmers believe it is in their interest to distort the responses. Possible reasons why farmers might intentionally understate irrigation are that they believe their responses will be used for tax purposes or, for farmers receiving federally subsidized water, they want to conceal how much water they actually receive.[1] The reliance on mail responses by farmers in 1974 and 1969 as opposed to the personal interviews used in earlier censuses could account for the increase in underreporting, which appears to be greatest in 1974 and significant in 1969. The 1978 census used a direct enumeration area sample to make statistical estimates for farms missed in the initial mailing response but had no means of adjusting for underreporting among the respondents.

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[1] The 1967 CNI data are in Basic Statistics--National Inventory of Soil and Water Conservation Needs, 1967, U.S. Department of Agriculture, Statistical Bulletin No. 461, January 1971. The 1977 NRI data are February, 1980 estimates of the 1977 SCS National Resource Inventories. These data were provided by the Soil Conservation Service. A national soil and water inventory also was undertaken for 1958 but this did not have irrigation data.

[2] As part of an agreement between the Statistical Reporting Service and the Federal Crop Insurance Corporation (FCIC), state statisticians do collect some irrigation data. In the West, for example, they collect data on corn in three states, wheat in fifteen states, sorghum in eight states, and cotton in four states. The state statisticians rely primarily on farmer reports for their information but the methods differ from state to state. These data are not regularly published but some states include them in their crop and livestock reports.

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[1] The states as well as the experts providing the U.S.G.S. and IJ estimates seldom rely on census data for irrigated acreage. Based on conversations with six of the state experts providing irrigation estimates for the IJ, this situation reflects a widespread belief that the census data are inaccurate. Unfortunately, as is discussed later in this appendix, rejection of the census numbers seldom means the states have better data upon which to base their estimates.

The 1978 agricultural census is being supplemented by the 1979 Farm and Ranch Irrigation Survey undertaken by the Bureau of the Census. This is a survey of about 10 percent of the irrigated farmers responding to the 1978 census. The survey provides more detailed farm level information on factors such as the nature of the irrigation facilities and practices, the crops grown, and their yields. This follow-on survey was undertaken in part to ease the respondent bruden of the census; the data should be available on tape about May 1981 and in published form sometime in 1982.

The Bureau of the Census also conducts an Irrigation Census of water distributors or irrigation organizations once every ten years. The most recent were done in conjunction with the 1959, 1969, and 1978 censuses of agriculture. Historically the irrigation censuses consistently show more acreage irrigated than the agricultural censuses. The 1959 census indicates that the irrigation organization reports overstate irrigated area because

"1. Some irrigation organizations report the area assessed for water, the area eligible to receive water, or the total area in farms receiving water. Usually these areas are considerably greater than the area irrigated during a year.

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[1] Several people interviewed in connection with this study, suggested that underreporting is common because many farmers believe the data are used for tax purposes, and showing higher levels of irrigation may make their operations more susceptible to scrutiny by local or federal tax authorities. Fred Ruggles of the Bureau of Census also indicated that underreporting of irrigated acreage is a problem among California farmers receiving more federally subsidized water than they are entitled to receive.

2. In some cases, two or more irrigation organizations provide water used to irrigate the same area. In such cases, the same area is counted by each of the organizations supplying the water."[1]

A discussion with a Census official suggests these problems persist with the more recent irrigation censuses.[2] Consequently, the acreage estimates of the irrigation censuses are not presented in this study.

The 1967 Conservative Needs Inventory (CNI) and the 1977 National Resources Inventory (NRI) also provide primary irrigation acreage estimates for all states. Although listed under different titles, these estimates represent a generally consistent effort by the Soil Conservation Service (SCS) to describe the use and conservation needs of rural land. One byproduct of the 1967 and 1977 surveys is the calculation of irrigation acreages of crop groups by state and land class. Unlike the census, the CNI and NRI estimates are not dependent on farmer responses for accuracy. They are based on detailed, on-site inspection of sample points of all nonfederal rural land. The 1977 sampling rate and techniques were designed to achieve a 95 percent confidence level with a coefficient of variation of 1 to 3 percent in estimating land use such as irrigation. The sampling rate for the 1967 CNI was even higher.[3] Both surveys relied on trained personnel to gather the basic data at the randomly selected sites. The 1977 NRI data also were subjected to a quality check by a team of agronomists who resampled random sections.

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[1] U.S. Department of Commerce, U.S. Census of Agriculture: 1959, Final Report - Vol. III, Irrigation of Agricultural Lands, p. xxv.

[2] Conversation with Fred Ruggles, U.S. Bureau of the Census. Agriculture Division, January 30, 1981.

[3] For a description of the sampling techniques used for the 1967 inventory see Basic Statistics--National Inventory of Soil and Water Conservation Needs, 1967, p. 203. Information on the sampling techniques used for the 1977 inventory was provided by Ray Dideriksen of the Soil Conservation Service.

Unfortunately, the CNI and NRI irrigation data also have limitations for studying irrigation. As noted above, they include an unknown (but, at least for the West, probably small) amount of land that was not actually irrigated in the survey year. The data are not reliable at the county level, and, in states with little irrigation, the small samples result in wider percentage coefficients of variation. Furthermore, these inventories do not differentiate by crops but only by broad crop groups such as row crops and close-grown crops.

Although the 1967 CNI data were collected as described previously, other agencies, in particular the Forest Service, were allowed to adjust the data to meet their agency estimates. By allowing this adjustment process, however, the statistical properties of the survey were destroyed and its value as a primary source threatened. While the SCS staff are not sure what impact these changes had on the data, it appears that only the large groupings of land use were affected by these adjustments (i.e., totals of pastureland, cropland, forestland). Apparently the irrigation acreages were unaffected by the adjustments and still can be regarded as a primary source. The 1977 data were not subject to revision by other agencies.

A comparison with other land use estimates and discussions with SCS officials suggest the CNI and NRI surveys had difficulty in distinguishing between irrigated cropland pasture and irrigated permanent pasture. Although this problem does not affect the total of irrigated acres, it does indicate that the relative mix of the pasturelands should be used with discretion.

The census estimates cannot be compared directly to either the 1967 CNI or the 1977 NRI because of timing differences. However, if we assume that the change in irrigated acreage from 1967 to 1977 was linear in each state, irrigation estimates based on the CNI and NRI data can be derived for the 1969 and 1974 census years. (These projections are referred to as the CNI/NRI projections.) Table A-2 shows the 1969 and 1974 census data for the seventeen western states and the nation as a percentage of the CNI/NRI projections.

Nationwide the 1974 census estimate is only 73 percent of the CNI/NRI figure projected to 1974; for the West the census is 77 percent of the projection. The census figures are lower in all but one of the seventeen western states with the margin of difference exceeding 20 percent of the CNI/NRI figure in fourteen states. Only for Arizona is the census estimate within 10 percent of the CNI/NRI projection.

For 1969 the differences between the irrigated acreage estimates of the two sources are smaller but still substantial. The 1969 census estimate is 78 percent of the projected CNI/NRI national figure and 80 percent of the western total. In eleven of the seventeen western states the census figures are at least 20 percent below the 1969 CNI/NRI projections.[1]

While there are no other primary sources of irrigation data covering all states, Nebraska, New Mexico, and Texas have estimates of total acres irrigated in either 1977 or a census year. A comparison of these state estimates (which

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[1] For reasons discussed in the text, we might expect that the census estimates are a lower bound on the actual amount of irrigation in a census year. Yet, in two of the seventeen states the census data actually exceed the CNI/NRI projections. Given the manner in which we have projected the CNI/NRI estimates to the census years and the statistical error that could be introduced by the CNI and NRI sampling techniques, the 5 percent difference between the CNI/NRI projections and the census figures in Arizona is not surprising. And in view of the relative insignificance of irrigation in North Dakota, the reliability of CNI and NRI irrigation estimates for that state is lower than in the other western states.

Table A-2. Comparison of Estimates of Total Irrigated Acreage in the Seventeen Western States: 1974 and 1969 Census Estimates Expressed as a Percentage of the CNI/NRI Projections.

	1969	1974
Arizona	107	100
California	87	89
Colorado	77	74
Idaho	77	76
Kansas	79	73
Montana	80	69
Nebraska	71	68
Nevada	79	70
New Mexico	69	74
North Dakota	113	81
Oklahoma	92	70
Oregon	77	68
South Dakota	64	39
Texas	81	79
Utah	78	77
Washington	83	74
Wyoming	79	77
Western States	80	77
U.S. Total	78	73

Source: The notes to Table A-1 indicate the sources of the Census, CNI and NRI data.

use the census definition of irrigated land) with the census and NRI data (see table A-3) supports the view that the census data are grossly underestimated. This comparison also suggests that while the NRI data may provide a high estimate of irrigation in a given year, they are probably much more accurate than the census. The 1974 census estimates are 21, 33, and 23 percent below the respective state estimates for Nebraska, New Mexico, and Texas while the 1977 NRI estimates differ from the state estimates by 8 percent in Nebraska and 14 percent in New Mexico. For Texas, the state and the CNI/NRI projected estimates only differ by 4 percent for 1969 and 3 percent in 1974. Since Texas has been noted for systematically surveying its irrigated lands, this result lends credibility to the CNI and NRI estimates.[1]

SECONDARY SOURCES OF IRRIGATION DATA

There are several secondary sources of irrigation data. Three principal ones are the Irrigation Journal (IJ) with state estimates since 1951, the U.S. Geological Survey (USGS) with state estimates every five years from 1960 to 1975, and the Water Resources Council, which published the First and Second National Water Assessments, with estimates by water resource region for 1965 and 1975. These estimates are all accorded considerable attention if not credibility--the first because the numbers are published annually in a trade journal and the other two because they are included as part of major government water studies. The derivation of these estimates and their relation to the primary data are discussed below.

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[1] Texas conducts annual surveys of irrigation in the forty High Plains counties (which account for two-thirds of the state's irrigated land), and the Texas Department of Natural Resources in collaboration with other state agencies and the SCS has conducted state-wide irrigation surveys in 1958, 1964, 1969, and 1974. These surveys are considered to be accurate within 10 percent. Since there has been relatively little change in the state's total irrigation over the past decade, the error introduced by projections between survey years (as we have done with the CNI and NRI data) is probably small.

Table A-3. Comparison of State, Census and NRI Irrigation Estimates for Nebraska, New Mexico, and Texas (1000 acres)

		NRI[a]	State Sources	Census
Nebraska	1974	(5,840)	5,050	3,967
	1977	6,940	6,400 (prel.)	--
New Mexico	1974	(1,175)	1,294	867
	1977	1,167	1,358	--
Texas	1969	(8,549)	8,206	6,888
	1974	(8,334)	8,618	6,594

[a] The numbers in parentheses assume a linear trend between the 1967 CNI and the 1977 NRI estimates.

Sources

NEI data: Table A-1 indicates the sources of the NRI and CNI data.

State data: The New Mexico and Nebraska state irrigation estimates were provided by their respective state Crop and Livestock Reporting Services. See Nebraska Agricultural Statistics: Annual Report, 1976-1977, p. 91 and New Mexico Agricultural Statistics: vol. VIII, p. 7. The state irrigation estimates for Texas are from Texas Water Development Board Report 196, Inventories of Irrigation in Texas 1958, 1964, 1969, and 1974. October 1975, table 1, p. 60.

Census data: See sources to table A-1.

Irrigation Journal

Table A-4 presents the Irrigation Journal's state and regional estimates of irrigated land as a percentage of the 1967 CNI and 1977 NRI estimates and the 1969 and 1974 census estimates. The census estimates are considerably lower than the IJ estimates for both census years and for virtually every state. For the seventeen western states the IJ shows 26 percent more land irrigated in 1969 and 28 percent more in 1974 than the censuses. In contrast, the CNI and IJ totals for the seventeen western states are virtually the same for 1967 and the NRI and IJ data differ only by 2 percent for 1977. The national estimates of these sources differ by only 2 percent in 1967 and 5 percent in 1977. Underlying these aggregates, however, are wide variations in the estimates for individual states. The 1977 IJ acreages are within 10 percent of the NRI figures in only eight of the seventeen western states and the range is from 37 percent below the NRI level in Colorado to 68 percent above in Utah. A comparison of the 1967 IJ and CNI data shows even fewer states falling within the ± 10 percent range and the overall variations range from 26 percent below in New Mexico to 131 percent above in South Dakota.

The Irrigation Journal's annual irrigation surveys are based on data provided by experts in each state. Since each expert develops his own methodology for estimating state acreage, the data must be evaluated on a state-by-state basis. Since the IJ does not provide any basis for assessing the accuracy of the numbers, the individuals cited as the sources of the IJ

Table A-4. A Comparison of Alternative Estimates of Irrigated Acreage

	Irrigation Journal estimates as a percentage of:			
	SCS		Census	
	1967 CNI	1977 NRI	1969	1974
Arizona	104	98	97	100
California	105	92	117	113
Colorado	83	63	114	109
Idaho	104	101	136	135
Kansas	86	98	93	117
Montana	144	117	174	193
Nebraska	119	103	148	135
Nevada	104[b]	107	173	169
New Mexico	74	106	122	123
North Dakota	195	125	144	103
Oklahoma	111	114	118	147
Oregon	96	76	118	120
South Dakota	231	78	211[a]	143
Texas	93	108	126	131
Utah	89	168	133	173
Washington	103	84	119	120
Wyoming	83	88	108	123
17 Western States	100	98	126	128
U.S. Total	98	95	125	129

[a] The IJ 1969 estimate is an average of 1968 and 1970.
[b] An IJ 1968 estimate is used as a proxy for 1967.

Sources: The sources of the data used for these calculations are listed in table A-1.

data for six states, Idaho, Kansas, Montana, Nebraska, Texas, and Utah, were contacted.[1]

Among these states the recent IJ estimates for Texas came closest to being based on systematically acquired primary data.[2] At least in recent years the IJ Texas estimates have relied on the previously mentioned statewide and High Plains irrigation surveys; the 1974 IJ figure agrees with the 1974 Texas inventory estimate of 8.6 million acres, but the 1969 IJ estimate is 6 percent higher than the state's inventory figure.

The basis for the IJ's irrigation estimates in the other five states examined are highly questionable. In Kansas, for example, the irrigation data are based primarily on questionnaires filled in by county agents every several years. According to Delynn Hay,[3] who is in charge of these surveys, the responses of the county agents vary from those who fill out the questionnaire quickly with little attention to accuracy to those who take the task seriously and use tax records and other available information to systematically develop the data. Hay concluded that about 10 percent of the 1975 county responses could not be correct since they were so far out of line with those of the previous questionnaire taken in 1972. In such cases Hay adjusted the estimates of irrigated acreage to levels considered reasonable. The 1976 IJ data are the first numbers based on the 1975 Kansas survey. Estimates for the preceding several years are projections from the 1972 survey results.

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[1] These states were selected because they are important irrigation states with sizable discrepancies between the census and IJ estimates of irrigated acreage in 1974. For example, in the six states combined, the IJ shows 39 percent more acreage irrigated in 1974 than the census. We also attempted to include the states with the greatest percentage differences between the 1977 NRI and IJ data. Utah, for which the IJ shows 56 percent more acres irrigated than the NRI, represents one extreme. Colorado, for which the IJ shows 22 percent fewer acres irrigated, represents the other extreme. However, the 1977 Irrigation Journal survey lists no source for their Colorado data. Although the 1978 survey does list a source for Colorado, before this was available we had concluded from the responses by the six state sources contacted that the IJ data did not merit further attention.

[2] Wayne Keese, Extension Agricultural Engineer, Texas A&M University, is the source of IJ data for Texas.

[3] Delynn R. Hay, Extension Irrigation Engineer, Kansas State University, is the source of the IJ data for Kansas.

In Idaho the 1966 and 1975 base figures for land use were supplied by county SCS staff. These base year figures have been updated using data furnished by power suppliers, farmer applications to bring new land into irrigated production, and records of acreage converted to irrigation by sprinkler. Dorrell Larson,[1] the source of the IJ estimates for Idaho, indicates his data are accurate within 10 percent, and a comparison with CNI and NRI estimates supports this belief. The state estimates are virtually identical to the 1977 NRI and they differ by only 4 percent from the CNI estimates. In contrast, the IJ data are 35 and 36 percent above the 1974 and 1969 census estimates for Idaho.

Until approximately 1973 Montana's irrigation estimates were obtained by updating data based on surveys taken in the 1930s. Estimated growth trends in selected counties were extrapolated to obtain state estimates for subsequent years. These estimates were known to be overstated and, indeed, the 1967 IJ estimate is 44 percent higher than the CNI figure. According to J. E. Acord,[2] the source of the IJ's irrigation estimates, the state estimation techniques have improved since 1973. Montana's Water Resources Division's land classification now provides the base and this is updated by registrations of new irrigated acres. The law requiring farmers to register changes in irrigation is not strictly enforced, suggesting this method should understate the change in irrigation. Yet, the 1977 IJ estimate is still 17 percent above the NRI figure.

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[1] Larsen is an extension irrigationist with the Cooperative Extension Service, University of Idaho.

[2] J. E. Acord is an engineer with the Water Resources Division of the Montana Department of Natural Resources.

In Nebraska the IJ estimates of irrigated acres are compiled from the registration of water use by the state's Department of Water Resources. The data are based on farmers' registrations of the number of acres they intend to irrigate. The farmers, however, have an incentive to overstate their intentions in order to obtain larger water rights. Paul Fischbach,[1] the source of the IJ estimates, concludes that the estimates are somewhat high. And, indeed, the 1967 IJ estimate exceeds the CNI estimate by 19 percent and the 1977 IJ estimate exceeds the NRI estimate by 3 percent.

In Utah the IJ irrigation estimates rely on data from several sources including county agents and district soil conservation officials. Richard Griffin,[2] the source of the IJ estimates for Utah, explained that the IJ figure is too high because of duplication resulting from aggregating information from a variety of sources. Perhaps this explains why the 1977 IJ estimate for irrigated acreage is 68 percent higher than the NRI figure.

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[1] Paul Fischbach is an extension irrigationist with the University of Nebraska at Lincoln.

[2] Richard E. Griffin is an extension water resource specialist at Utah State University.

Inquiries into the Irrigation Journal's irrigation estimates in these six states did not instill confidence in the data. IJ data are not based on a systematic effort to survey irrigated lands. The methods used to obtain the data as well as the accuracy of the data not only differ among the states but vary over time within states. The Journal gives no indication as to the shortcomings of its estimates. On the contrary, the publisher would have his readers believe that his data are the basic facts on irrigated acreage.[1] While some of the state estimates may be reasonably accurate, many others are not. In some cases the sources of the estimates even felt obliged to apologize for their estimates. Unfortunately, the reader of the Irrigation Journal has no way of discerning which state estimates to trust. While the IJ's aggregate estimates of irrigation in the United States and in the West appear to be reasonably accurate, this appears to be a fortuitous result of offsetting errors in the estimates of individual states.

The U.S. Geological Survey

The USGS has published estimates of irrigated acreage for 1960, 1965, 1970, and 1975 as part of their studies of estimated water use in the United States.[2] Table A-5 presents their 1970 and 1975 data as a percentage of: (1) the CNI/NRI data projected to those dates, (2) the 1969 and 1974 census data, and (3) the 1970 and 1975 Irrigation Journal data.

It is readily apparent from table A-5 that the USGS figures are not based on census data. During both periods the censuses show considerably less

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[1] Dick Morey, "Crystal Balling the Irrigation Industry," Irrigation Journal, March/April 1977.

[2] These data are published in the following Geological Survey Circulars: 1960 in #456, 1965 in #556, 1970 in #676, and 1975 in #765.

Table A-5. A Comparison of Alternative Estimates of Irrigated Acreage

	USGS estimates as a percentage of:					
	CNI/NRI Projections		Census		Irrigation Journal	
	1970	1975	1970 USGS: 1969 Census	1975 USGS: 1974 Census	1970	1975
Arizona	108	121	102	121	103	122
California	104	103	120	116	101	103
Colorado	121	80	159	108	136	99
Idaho	102	98	134	133	98	94
Kansas	86	103	118	149	96	120
Montana	94	93	120	136	69	77
Nebraska	94	90	144	141	93	100
Nevada	84	75	110	111	64	65
New Mexico	93	94	134	127	110	103
North Dakota	119	138	117	183	80	141
Oklahoma	103	130	118	194	100	132
Oregon	94	89	125	135	103	108
South Dakota	57	48	101	132	71	81
Texas	98	104	120	130	100	100
Utah	99	137	127	175	95	90
Washington	91	88	114	122	96	100
Wyoming	89	90	112	116	98	93
17 Western States	99	98	126	129	98	99
U.S. Total	97	93	128	131	100	100

irrigation in virtually all states; the USGS totals for the seventeen western states and the United States range from 26 to 31 percent above the prior year census estimates. These differences are much too large to be explained by one year's growth of irrigated acreage.

The USGS estimates for the West are much closer to the 1970 and 1975 CNI/NRI projections based on a linear change between 1967 and 1977. For example, these estimates of total irrigated acres in the West differ by only 1 percent in 1970 and 2 percent in 1975. Again, however, the aggregates hide large variations in the estimates for individual states. The USGS estimates differ from the CNI/NRI projections by 10 percent or more in six western states in 1970 and in eleven western states in 1975.

On balance, the 1975 USGS state estimates appear more reasonable than those of the Irrigation Journal. However, these two sources have some unfortunate features in common. First, while the aggregate estimates for the nation and the West seem reasonable, this is due in large part to offsetting errors in the estimates for the individual states. Secondly, neither source defines irrigated land and establishes a clear methodology for estimating irrigated acreage. The USGS estimates are supplied by their district offices. The district offices in turn follow the pattern of the Irrigation Journal and rely on local experts. No primary data are collected for the USGS estimates and each district apparently develops its own methodology for making estimates.

National Water Assessments

The Water Resources Council's (WRC) 1965 and 1975 assessments of the nation's water resources include estimates of irrigated land. Comparisons with all but the USGS estimates are limited to the national totals since the WRC regions are defined along hydrological and not political boundaries.

The Second National Assessment has alternative estimates of 1975 irrigation--the National Future (NF) figure of 45.3 million acres and the State/Regional Future (SRF) figure of 51.9 million acres (see table A-1). An initial estimate for the assessment was made by the Department of Agriculture based on a combination of Statistical Reporting Service county data for 1971-73 and 1969 census data updated to 1972. The 1972 estimates were then projected to 1975. Representatives of the River Basin Commissions, state agencies, and others were asked to comment on the resulting 1975 estimates for their regions. This review led to the inclusion of two estimates: the National Future estimate was derived primarily by participating federal agencies and the State/Regional Future estimate incorporates the inputs of the more local groups. Despite the considerable range of these alternatives both are at least 10 percent higher than the 1974 census figure and at least 10 percent less than the CNI/NRI figure projected to 1975.

Regional comparisons of the assessment and USGS data show variations similar to those noted earlier with the comparison of alternative estimates of state irrigation, that is, similarities in aggregate figures mark wide variations in the components. For example, the high (SRF) estimate of the Second Assessment is only 3 percent less than the USGS 1975 figure. But compared to the USGS, the SRF estimates for individual water resources regions range from 50 percent less in New England to 15 percent above in the Upper Colorado.

SOME CONCLUSIONS

The deficiencies of the census data leave us without a data base which is simultaneously detailed for crops and counties, comprehensive for the entire nation, and reliable. The 1967 CNI and 1977 NRI data appear to be the most reliable estimates available for all states. For analytical purposes, however, they have several shortcomings--they are available for only 1967 and 1977, they are not considered accurate at the county level, they do not provide data for individual crops, and they may overstate the acreage actually irrigated in the survey years since, by definition, they include lands where water is supplied as part of a cropping system. Despite these shortcomings, they appear to be the most reliable estimates of irrigated acreage, and this analysis relies on the CNI and NRI data whenever possible. When more detail is required, adjusted census data, state survey data, or SRS survey data are used, depending on which seems more appropriate. One method used for adjusting the census data is to assume that (1) the CNI/NRI state estimates projected to the 1969 and 1974 census years more accurately reflect the true quantity of acres irrigated and (2) the errors in the census estimates are proportional among crops.[1]

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[1] A comparison of the census crop breakdowns with the CNI and NRI percentages of row and close-grown crops support this second assumption at the level of the USDA's farm production regions.

GROWTH AND PROSPECTS FOR IRRIGATION IN THE EASTERN UNITED STATES

by
James C. Hanson
and
James Pagano
Resources for the Future
Washington, D.C. 20036

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James C. Hanson
June 22, 1981

GROWTH OF EASTERN IRRIGATION[1]

THE REGION AS A WHOLE

While irrigation has historically been associated with the arid western states, in the past three decades it has become increasingly important in the East. In 1950, only 6 percent of the 25.8 million acres of irrigation in the United States was located in the thirty-one eastern states.[2] By 1977, the East's share had risen to 17 percent (table 1). Between 1950 and 1974, eastern irrigation grew at an annual rate of 4.6 percent according to the Census of Agriculture, while the West grew at only 1.7 percent.[3] The NRI/CNI put the East's rate of growth between 1967-1977 even higher--5.6 percent or almost three times that of the West (1.9 percent) for that period. Eastern irrigated acreage increased by

---

[1] There are two sources of primary data on U.S. irrigation with nationwide coverage: the U.S. Census of Agriculture, which is taken every five years (1974 is the most recent year available); and the surveys by the U.S. Department of Agriculture Soil Conservation Service in 1967 and 1977, titled respectively the Conservation Needs Inventory (CNI) and the National Resources Inventory (NRI).

While the Census provides detailed information on irrigated acreage and crops as far back as 1939, its acreage estimates are generally considered by state irrigation experts to be too low. The CNI/NRI estimates are higher and probably more accurate. Unfortunately, this data starts only in 1967 and does not include information on specific crops. This report draws on both sources, using whichever one provides the most accurate and current data on the topic being discussed.

For a detailed discussion on primary as well as secondary data on irrigation, see the appendix of the study of western irrigation which is included as the first part of this report.

[2] U.S. Census of Agriculture, 1950, Vol. III, Table 2, page 35.

[3] U.S. Census of Agriculture, 1974, Vol. I, Part 51, Summary and State Data, Chapter 4.

Table 1. Estimates of Irrigated Acreage in Various Years for 31 Eastern States (thousands of acres)

States	1967 CNI	1977 NRI
Maine	22	22
New Hampshire	3	--
Vermont	--	7
New York	97	75
Massachusetts	29	18
Rhode Island	5	--
Connecticut	27	8
New Jersey	145	155
Pennsylvania	54	10
Delaware	30	37
Maryland	29	39
Northeast total	440	371
West Virginia	--	10
Virginia	--	88
North Carolina	--	271
Kentucky	--	9
Tennessee	--	36
Appalachian total	--	414
Minnesota	15	398
Wisconsin	114	340
Michigan	--	228
Lake States total	129	966

Table 1. (Continued)

States	1967 CNI	1977 NRI
Iowa	23	82
Illinois	34	66
Indiana	19	140
Ohio	12	48
Missouri	118	776
Corn Belt total	206	1,112
Arkansas	1,765	2,449
Mississippi	182	354
Louisiana	1,572	1,211
Delta States total	3,520	4,014
South Carolina	--	44
Georgia	--	676
Alabama	--	37
Florida	1,694	2,667
Southeast total	1,694	3,424
Eastern States total	5,988	10,301
Western States total	41,488	50,236

Source: 1967 Conservation Needs Inventory (CNI) - USDA, Basic Statistics --National Inventory of Soil and Water Conservation Needs, 1967, Statistical Bulletin No. 461. 1977 National Resource Inventory (NRI) - USDA, 1977 SCS, National Erosion Inventory, Feb., 1980.

4.3 million acres between 1967 and 1977, and western irrigated acreage by 9.9 million acres (table 1). Despite its relatively fast growth, however, irrigated land in the East in 1977 still was less than 4 percent of total eastern cropland and pasture. Within the region the Delta had the largest proportion of irrigated land, but it was only 12 percent (table 2).

DISTRIBUTION WITHIN THE REGION

Until World War II, most irrigation in the East was found in the rice-growing states of the Delta and in Florida. In 1939, the 559,000 acres of irrigated rice in the Delta alone accounted for 76 percent of the total irrigated acreage in the East. Most of the remaining acreage consisted of Florida's irrigated fruit and vegetable crops. Both Florida and the Delta states used furrow and flooding as a means of distributing water. With the advent of lightweight aluminum tubing and advances in sprinkler technology after World War II, the extent and nature of eastern irrigation changed significantly. The hand-move sprinkler systems that were developed required large amounts of labor and capital investment, generally limiting their use to high-valued crops. Vegetable, tobacco, and orchard irrigation in Florida and the Northeast expanded with this type of irrigation. By 1969, 31.6 percent of eastern irrigation was in high valued crops (peanuts, tobacco, orchards, potatoes, vegetables; table 3). Rice's share, meanwhile, had fallen to 23 percent of irrigated acreage. In 1969, however, eastern irrigation was already shifting out of high value crops. The development of self-propelled sprinklers had drastically reduced labor requirements and operating costs, allowing

Table 2. Comparison of Irrigated and Nonirrigated Cropland and Pasture Use in the Eastern United States, 1967-1977

	Irrigated Cropland and Pasture as a Percentage of Total Cropland and Pasture	
	1967	1977
Northeast	1.8	1.7
Appalachian	--	1.1
Lake States	.2	1.9
Corn Belt	.2	1.0
Delta States	11.5	11.9
Southeast	5.7	10.9
31 Eastern States	2.0	3.5

Source: Calculated from 1967 CNI and 1977 NRI data referenced in table 1.

Table 3. Irrigated Acreage by Crop Group in 31 Eastern States, 1969 and 1974 (percentages of total acres irrigated in the East)[1]

		1969	1974
Grains:	Total	28.1	40.2
	Corn for all purposes	4.6	6.1
	Sorghum for all purposes	.4	.3
	Wheat	.4	.3
	Rice	22.7[2]	33.5
Soybeans		11.3	6.2
Peanuts		.5	.8
Hay		1.1	.9
Pasture		9.0	10.3
Cotton		5.7	3.2
Tobacco		2.7	2.0
Orchards		13.8	13.2
Potatoes		3.6	3.4
Vegetables		11.0	9.7
Other		13.3	9.9

[1] Source: Census of Agriculture, 1969 and 1974, tables 1 and 11.

[2] 1969 rice acreage derived from data in 1969 Census, vol. V, table 13.

Note: Peanuts, tobacco, orchards, potatoes, and vegetables are considered high-value crops.

lower value field crops to be irrigated--particularly corn and soybeans. In addition, these systems could be used on hillier, sandier soil. Expansion in irrigated acreage followed as this new technology was adopted as in the Corn Belt, Lake States, and, most dramatically, the Southeast. Georgia and Florida alone accounted for over 38 percent of the growth in eastern irrigation between 1967 and 1977 (table 4). The Lake States contributed almost 20 percent of the East's growth. Irrigation in the Delta States continued to grow, but at a slower rate than in the Southeast, Lake States, and Corn Belt. Consequently the Delta States' share of eastern irrigation declined from 60 percent in 1967 to 40 percent in 1977. The Appalachian states made modest gains, while the Northeast declined in acreage.

Table 5 shows the range of crops grown in 1974. In that year rice still was the dominant irrigated crop in the East, accounting for over one-third of all irrigated acres, although it was confined almost exclusively to the Delta States. Orchards and pasture ranked second and third in importance and were the major irrigated crops in the Southeast. Irrigated vegetables, soybeans, and corn accounted for half of the remaining acreage and were distributed in various regions--soybeans mostly in the Delta; corn in the Lake States and Corn Belt; and vegetables in every region save the Delta. Potatoes, cotton, tobacco, hay, and various other crops accounted for the remaining acreage. The crops of most interest to this study (corn, wheat, sorghum, cotton, and soybeans) occupied 16.1 percent of the total irrigated acreage. Among these crops corn and soybeans were most important, with a little over 6 percent each of total

Table 4. Growth of Irrigated Acreage in the East by Farm Production Region, 1950-1977

	Acres irrigated as a % of Eastern irrigation			Change in irrigated acres by region 1967-77 (percentage)	Regional changes in irrigation as a % of the total increase in Eastern irrigation, 1967-77
	1950	1967	1977		
Northeast	5.7	7.3	3.6	-15.7	-1.6
Appalachian	--	--	4.0	-	9.6
Lake States	1.8	2.2	9.4	648.8	19.4
Corn Belt	1.1	3.4	10.8	439.8	21.0
Delta States	66.2	58.8	40.0	14.0	11.4
Southeast	24.7	28.3	33.2	122.8	40.1
Florida	(24.7)	(28.3)	(25.9)	(138.9)	(22.6)
Georgia	(--)	(--)	(6.6)	(--)	(15.7)
S.C., Ala.	(--)	(--)	(.8)	(--)	(1.9)
31 Eastern States	100.0	100.0	100.0	72.0	100.0

Sources: 1950 data taken from U.S. Census of Agriculture, 1950, Vol. III, Table 2, p. 35: 1967 CNI and 1977 NRI references are listed in the footnote to Table 1.

Table 5. Irrigated Acreage of Selected Crops by Region for the East in 1974 (Percentage of total acres irrigated in each region)

	Grains							
Region	Total	Corn	Sorghum	Wheat	Rice	Soybeans	Peanuts	Hay
Northeast	4.7	4.0	--	0.7	--	3.0	--	1.1
Appalachian	7.8	6.7	0.1	0.7	.3	3.1	0.4	1.8
Lake States	25.9	24.9	--	1.0	--	2.5	--	3.1
Corn Belt	46.1	38.0	2.6	2.5	3.0	25.6	--	1.7
Delta States	82.1	0.3	0.2	--	81.6	8.8	--	0.4
Southeast	3.9	3.7	0.2	--	--	1.4	2.1	0.9
31 Eastern states	40.2	6.1	.3	.3	33.5	6.2	.8	.9

Region	Pasture	Cotton	Tobacco	Orchards	Potatoes	Vegetables	Other
Northeast	0.5	--	2.3	6.6	17.8	46.2	17.7
Appalachian	1.8	0.7	63.9	1.2	4.0	11.6	3.5
Lake States	0.4	--	--	1.8	23.0	25.6	17.5
Corn Belt	0.9	5.3	0.1	1.0	2.9	9.5	6.9
Delta States	.9	6.7	--	0.1	--	0.3	0.7
Southeast	25.7	0.2	1.3	33.1	1.4	11.8	18.3
31 Eastern states	10.3	3.2	2.0	13.2	3.4	9.7	9.9

Source: 1974 Census of Agriculture, Vol. I, Part 51, Summary and State Data, Chapter 4.

irrigated acreage. However, corn acreage has grown rapidly since 1974.[1]

IRRIGATION TECHNOLOGIES

Sloggett provides an estimate of the acreage irrigated by different distribution systems in 1977.[2] His estimate covers only irrigation water pumped from an on-farm source, be it surface or groundwater. However, this comprises almost all eastern irrigation. Minor exceptions include a small number of Soil Conservation Service (SCS) projects and Corps of Engineer dams, and a small quantity of land in Florida irrigated using water table control (i.e. wetlands which are irrigated by reversing the drainage process and allowing the water table to rise again to the root zone). Fifty-seven percent of the land irrigated with pumped, on-farm water used surface distribution methods (i.e., flood, furrow). Most surface irrigated land (98 percent) was found in the Delta States and Florida. The sprinklers which irrigated the remaining 43 percent of the land were scattered throughout the eastern states. Center pivots are the predominant sprinklers in the Corn Belt and the Lake States where there are large fields. Big guns are used more extensively in the Southeast, where the fields are smaller and irregular (table 6). The predominant sprinkler in the Northeast has been hand-moved where it is used on vegetables primarily, although the center pivot has come into wide use in such states as Maryland and Delaware.

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[1] Between 1973-1979, corn acreage grew at a rate of 42.6 percent per annum in Georgia and at a similar rate in Michigan between 1970 and 1977. See p. 16 below.

[2] Gordon Sloggett, Energy and U.S. Agriculture: Irrigation Pumping, 1974-77, USDA, ESCS, Agricultural Economic Report no. 436, September, 1979. Sloggett's estimate of acreage for 1977 is 30 percent lower than the NRI's (7.3 million acres vs. 10.3 million). This is in part due to Sloggett's omission of any irrigation which does not use on-farm, pumped water. Also, Sloggett drew his acreage figures from various state sources, while the NRI conducted its own survey using primary sources. Finally, Sloggett's estimate was only for 1977 while the NRI was for land irrigated in 1977 or in at least two of the previous three years.

FACTORS AFFECTING GROWTH OF EASTERN IRRIGATION

The primary purpose of irrigation is to compensate for lack of moisture. The need for irrigation in the arid West is obvious. However, in the East rainfall is adequate in most years for most crops. Not surprisingly, eastern irrigation has historically been devoted to rice, a crop requiring flooding. However, eastern farmers irrigate in two other circumstances of water deficiency--in occasional years of low rainfall (drought) and on soils that do not retain water well (droughty soils). Irrigation in these circumstances has become increasingly economical because of two factors. First, improvements in irrigation technology have made irrigation cheaper and more versatile. The modern, self-propelled sprinkler systems have not only drastically reduced the labor cost of irrigation but are also less capital-intensive on a per-acre basis than the old, hand-moved systems. Moreover, center pivots can operate on sandier, hillier terrain with slopes up to 9 to 10 percent. Second, the complementary inputs to irrigation water--fertilizers, pesticides, herbicides, machinery, and land itself--have grown both more expensive and more productive. This means that the "penalty" paid in lower yields and unrecovered costs of chemical inputs during drought years is higher than before while, conversely, the reward for having the right amount of water

Table 6. Acreage irrigated with onfarm pumped water by types of distribution system and farm production region in 1977 (1000 acres)

	Big Gun	Center Pivot	Other Sprinkler	Surface
Northeast	25.9	42.6	229.8	5.6
Appalachia	27.6	8.1	181.4	5.9
Lakes States	178.8	440.1	120.3	11.8
Corn Belt	84.0	233.5	77.3	236.2
Delta States	25.8	28.7	43.6	2563.8
Southeast	685.1	167.9	554.0	1303.0
Florida	(376.6)	(21.5)	(334.8)	(1301.0)
Georgia	(256.6)	(129.1)	(191.3)	(0)
Ala., SC	(51.9)	(17.3)	(25.9)	(2.0)

Source: Gordon Sloggett. Energy and U.S. Agriculture: Irrigation Pumping, 1974-77, USDA, ESCS. Agricultural Economic Report No. 436. September, 1979.

at the right time is greater. Indeed, the investment in modern machinery and chemicals may not be justified if the complementary input of water cannot be guaranteed. The rise in land values has increased the attractiveness of irrigation equipment as a substitute for land.[1] Irrigation equipment has the added attraction that, in contrast to land, it is depreciable, a distinct advantage for tax purposes.

Much of the expansion in irrigation in the Corn Belt has been in response to droughts. Researchers in Iowa have confirmed high interest in irrigation in years of inadequate rainfall, but when the rains come interest wanes. With rising costs of energy and of financing for irrigation equipment, farmers in the Corn Belt likely will find irrigation a less attractive form of risk insurance than in the past.[2]

The second type of water deficit occurs where there is enough rain but soils cannot retain it. Two major factors that affect the water holding capacity of a soil are its texture and depth. Texture affects the rate of infiltration plus the ability of the soil particles to hold the water. Depth affects the potential reservoir of water from which a plant can draw. Generally, the coarser the texture and the shallower its depth, the more droughty a soil will be. Sands and loamy sands tend to be the soils that are droughty and responsive to irrigation, as are silt loams, loams, and sandy loams that are shallow over a coarse rock and sand layer. In these situations not only does irrigation provide protection against the occasional year with less than adequate rainfall, but it also increases yields significantly every year.

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[1] Data comparing the relative cost of land and irrigation equipment are not readily available. However, table 7 demonstrates the rise in land prices relative to prices of agricultural production inputs in three eastern states where irrigation has grown significantly.

[2] Personal communication with John Miranowski, Iowa State University, Agricultural Economics Department, November 1, 1979.

REGIONAL PERSPECTIVE

Regions Not Studied

The Northeast and Appalachia are excluded from the analysis primarily because of the small role they play in eastern irrigation (3.6 percent and 4.0 percent of irrigated land, respectively, table 4). Also, the major irrigated crops in these regions are not those of interest in this report. In 1974, 64 percent of the irrigated acreage in Appalachia was planted to tobacco, while in the Northeast, 64 percent was in potatoes and vegetables (table 5). The Northeast also declined in irrigated acreage between 1967 and 1977.

The Corn Belt is excluded because of its small irrigated acreage and the apparent limited potential for additional growth, as noted above. Seventy percent of irrigated land in the Corn Belt is in Missouri, and about two-thirds of that is in the Southeast corner of the state on Mississippi Delta soils. Irrigation potential in this area is analyzed in a study by a group at the University of Arkansas, which is included as the third part of this report on irrigation in the United States. Over

Table 7. Prices of Agricultural Land Relative to Prices of Other Agricultural Inputs for Georgia, Minnesota and Wisconsin

	Index of Production Item Prices as Percentage of Index of Land Prices									
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
Georgia	83	78	74	69	73	63	61	65	62	61
Minnesota	93	92	93	95	101	89	75	66	54	52
Wisconsin	91	87	82	82	81	76	76	71	62	57

Source: USDA, Agricultural Statistics 1973, 1977, 1979.

95 percent of the irrigated land in Indiana, the Corn Belt state with the second largest amount of irrigated land, is in a small section in the northern part of the state where soils are sandy, similar to those in parts of Wisconsin and Michigan.[1] If the Delta soils of Missouri and the sandy soils of Indiana are excluded, the NRI estimate for irrigated acreage in the Corn Belt is reduced 55 percent to 484,000. The Delta region is excluded here since, as noted above, it has been studied by May, Shulstad and Erstine at the University of Arkansas.

The Southeast and Lake States

Growth has been rapid in these two areas. The most spectacular gains have been made by field crops. In Georgia between 1973 and 1979 annual growth in irrigated acreage averaged 27.7 percent (table 8). Irrigated corn grew at 42 percent annually, going from Georgia's third most important irrigated crop in 1973 to the most important in 1979. Irrigated land in soybeans made even more dramatic gains, rising 80 percent per year on average. Michigan followed a similar pattern between 1970 and 1979 with rapid growth (47 percent annually) in field crops, mostly corn, which, as in Georgia, was the most important irrigated crop in 1979 (table 9). Likewise, in Minnesota, the most important state for irrigation in the Lake region, corn accounted for 79.0 percent of 1979's irrigated acreage (table 10).

Why was there such significant growth in these areas? As mentioned above the key seems to be droughty soils. Both the Lake States and the

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[1] Task Force--DOI, USDA, and EPA. Irrigation Water Use and Management--Interagency Task Force, U.S. Government Printing Office, Washington, D.C., June 1979, p. 107.

Table 8. Comparison of Irrigated Crop Acreages in Georgia Between 1973 and 1979 (1,000 acres)

	1973		1979		
Crops	Acres	% of Total	Acres	% of Total	Annual Growth Rate (%)
Corn	39.3	20.3	330.1	39.2	42.6
Peanuts	64.0	33.0	255.0	30.3	25.9
Soybeans	3.3	1.7	113.8	13.5	80.4
Cotton	1.4	0.7	6.9	0.8	30.5
Orchard & vegetable	30.8	15.9	64.7	7.7	13.2
Hay & pasture	3.2	1.7	8.1	1.0	16.7
Tobacco	48.3	24.9	45.5	5.4	- 1.0
Other	3.6	1.9	18.1	2.1	30.9
Total	193.9	100	842.2	100	27.7

Source: Robert Skinner, Irrigation Survey, 1975, and Irrigation Survey, 1979, Cooperative Extension Service Bulletins, University of Georgia, February 4, 1976 and April 1, 1980, respectively.

Table 9. Comparison of Irrigated Crop Acreages in Michigan Between 1970 and 1977 (1,000 acres)

	1970		1977		
	Acres	% of Total	Acres	% of Total	Annual Growth Rate (%)
Field crops*	11.6	11.3	172.8	53.2	47.1
Potatoes	22.4	21.8	32.3	9.9	5.4
Hay and Pasture	.7	.7	11.4	3.5	49.0
Vegetables and orchard	38.3	37.3	59.1	18.2	6.4
Other	29.0	28.3	49.3	15.2	7.9
Total	102.6	100.0	324.9	100	17.9

*Field crops are composed mostly of corn.

Source: Douglas J. Bedell and Ronald L. Van Til, Irrigation in Michigan, 1977, Water Management Division, Michigan Department of Natural Resources, December 1979.

Table 10. Irrigated Crop Acreages in Several States in 1979 (1,000 acres).

<table>
<tr><th></th><th>Corn</th><th>Cotton</th><th>Wheat</th><th>Peanuts</th><th>Soybeans</th><th>orchard & vegetables</th><th>Hay & Pasture</th><th>Other</th><th>Total</th></tr>
<tr><td>Minnesota</td><td>355.0</td><td>--</td><td>--</td><td>--</td><td>5.0</td><td>27.5</td><td>16.0</td><td>47.0</td><td>450.5</td></tr>
<tr><td>Wisconsin</td><td>89.6</td><td>--</td><td>--</td><td>--</td><td>2.1</td><td>12.8</td><td>28.9</td><td>119.6</td><td>253.0</td></tr>
<tr><td>Michigan</td><td>153.1</td><td>--</td><td>--</td><td>--</td><td>16.8</td><td>54.8</td><td>11.9</td><td>104.4</td><td>341.0</td></tr>
<tr><td>Georgia</td><td>330.1</td><td>6.9</td><td>--</td><td>255.0</td><td>113.8</td><td>64.7</td><td>8.1</td><td>63.6</td><td>842.2</td></tr>
<tr><td>South Carolina</td><td>18.8</td><td>--</td><td>--</td><td>.9</td><td>9.2</td><td>26.1</td><td>1.6</td><td>6.0</td><td>62.6</td></tr>
<tr><td>Alabama</td><td>49.8</td><td>2.7</td><td>--</td><td>37.1</td><td>19.3</td><td>2.4</td><td>.8</td><td>9.2</td><td>121.3</td></tr>
<tr><td>Florida[1]</td><td colspan="5">78.9</td><td>31.2</td><td>12.0</td><td>9.6</td><td>131.7</td></tr>
</table>

[1] For 26 Northwest counties.

Sources: Minnesota - Irrigation Journal, Volume 29, No. 6, December 1979; Michigan - same as Minnesota; Wisconsin - same as Minnesota; Georgia - Robert Skinner, Irrigation Survey, 1979, Cooperative Extension Service, College of Agriculture, University of Georgia; South Carolina - C. V. Privette, County Agent's Irrigation Surve[illegible]operative Extension Service Bulletin, 11/79, Clemson University; Alabama - Larry M. Curtis, "1979 A[illegible] Irrigation Survey," Agriculture and Natural Resources Information, SW 79-5, Cooperative [illegible]n Service, Auburn University; Florida - Unpublished Data from 1979 County Agent survey provided [illegible] J. C. Good, Department of Agricultural Engineering, University of Florida, Gainesville.

Southeast have large acreages of sandy soils (figure 1). An irrigation map of these states would show a high degree of correspondence between the sandy soils and irrigated regions.[1] It is on these soils that irrigation makes a difference as table 11 illustrates. The yield advantage of irrigation ranges from 50 to 100 bushels an acre for Alabama, Indiana, and Minnesota. These yield results for Indiana are taken from land in the northern part of the state where there is a predominance of sandy soil similar to the glacial outwash found in the Lake States. In the East, the highest net returns to irrigation generally occur on poor soils where the yields are traditionally low--the opposite of the West, where the best land is irrigated.

Another reason for the growth in these areas is the introduction of self-move irrigation systems. In Georgia between 1973 and 1977, hand-move irrigation systems decreased as a percentage of all units in the state from 83.4 to 34 percent. On the other hand, self-move systems (traveller and center pivot) increased from a combined percent of 12.1 to 62.3 (table 12). These systems reduce the labor requirements and increase the acres that could be irrigated with a single system. An example of the financial advantage of irrigation can be seen in South Carolina where net returns to irrigated corn and soybeans averaged $50/acre more than returns on non-irrigated land (table 13).

The center pivots are most popular in the Lake States, where field sizes are larger and more regularly shaped than in the Southeast. In contrast, the travellers are much more important in the Southeast because of the smaller, more irregularly-shaped fields (table 14).

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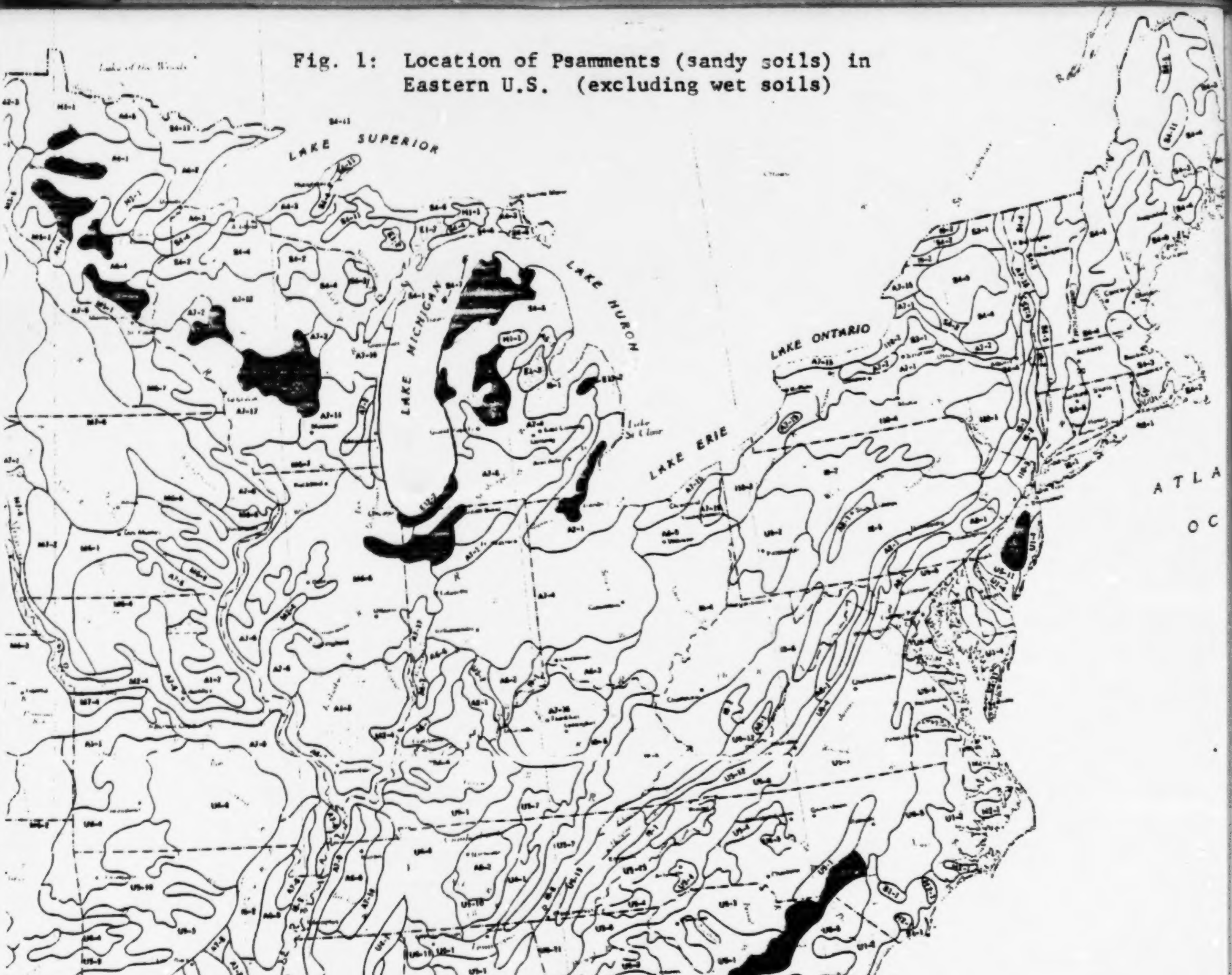
[1] The map does not mark the wet sandy soils found in the Southeast Coastal regions.

Fig. 1: Location of Psamments (sandy soils) in Eastern U.S. (excluding wet soils)


Lake of the Woods
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
Lake St Clair
LAKE ONTARIO
LAKE ERIE
ATLA
OC

Source: U.S. Geological Survey Sheet Number 86 "Distribution of Principle Kinds of Soils" 1969.

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Table 11. Irrigated and Nonirrigated Corn Yields on Sandy Soil in Alabama, Indiana, and Minnesota

States	Dates of Testing	Corn Yield (Bu/Acre) Irrigated	Nonirrigated	Difference in Yield
Alabama	1971-1978	102	53	49
Indiana	1948-1964	131	58	73
Minnesota				
North Central	1970s	110	30	90
Central	1970s	130	40	90
South Central	1970s	160	50	110

Sources: Alabama: Larry M. Curtis and Wade F. Faw, The Potential for Irrigated Corn Production in Alabama, Bulletin EAI-80, Alabama Cooperative Extension Service, Auburn University, 1980. Indiana: P. R. Robbins and others, Irrigation of Field Crops in Indiana, ID-119(1977), Cooperative Extension Service, Purdue University. Minnesota: Vernon Eidman, Irrigation in Minnesota, No. 592, August-September, 1977, Agriculture Extension Service, University of Minnesota.

Table 12. Comparison of the Relative Quantities of Various Irrigation Systems in Georgia in 1973 and 1979

System	1973 (percent)	1979 (percent)
Center pivot	3.1	24.1
Traveller	9.0	38.2
Side roll	.1	.3
Hand-moved	83.4	34.0
Other	4.4	3.4
Total	100.0	100.0

Source: Robert Skinner, Irrigation Survey, 1975, and Irrigation Survey, 1979, Cooperative Extension Service Bulletins, University of Georgia, February 4, 1976 and April 1, 1980, respectively.

Table 13. Returns to Management and Risk for Irrigated and Nonirrigated Corn and Soybeans in South Carolina in 1980.

1980 Current $	Returns/Acre		Increase due to Irrigation
	Irrigated	Nonirrigated	
Crop			
Corn	50.99	-1.91	52.90
Soybeans	89.82	36.80	53.02

Corn: Irrigated yields (150 bu/acre) and dryland yields (80 bu/acre) with $2.75/bushel corn prices. Six acre-inches of water were applied through a 200 acre center pivot system. Production costs for 1980 were estimated and 1979 yields were used.

Soybeans: Irrigated yields (50 bu/acre) and dryland yields (30 bu/acre) with $7.25/bushel soybean prices. Four acre-inches of water were applied through a 200 acre center pivot system. Production costs for 1980 were estimated and 1979 yields were used.

Source: Farm Management Budgets, Department of Agricultural Economics and Rural Sociology, Clemson University, 1980.

Table 14. Irrigation Distribution Systems in Several States in 1979.

	Expressed as a Percentage of all Distribution Systems				
State	Center Pivot	Traveller	Side-roll	Hand Moved	Other
Minnesota	62	28	2	1	7
Wisconsin[1]	37	19	5	11	28
Michigan	n/a	n/a	n/a	n/a	n/a
Georgia	23	36	--	32	9
South Carolina[2]	32	31	--	31	6
Alabama	11	30	--	4	55[3]
Florida[2,4]	47	30	├──	──	── 23

[1] 1977 data.

[2] Acres irrigated by type of system as % of all irrigated acres.

[3] Mostly solid set.

[4] For 26 Northwest counties.

Sources: Same as table 9 except for: Wisconsin - 1977 Irrigation Data Survey by Soil Conservation Service and University of Wisconsin Extension.

With all this recorded growth in acreage, there have been factors, nonetheless, which have been impeding growth in these states, namely, energy and investment costs. Electricity is the major fuel for irrigation in the Lake States. Diesel is the major fuel in the Southeast (table 15). Because of diesel's high price and problems with supply, researchers expect a gradual phase-out of diesel as a fuel in this area.[1] The major impetus for change to electricity is its supply stability and lower cost. A problem in conversion to electricity is the fixed cost necessary for conveyance (i.e., laying a line out to the field). However, the operating costs associated with energy are not as crucial as in the West. In the West, operating costs are much higher where farmers might apply a minimum of 24 acre-inches a year to their crops. In the Southeast in an average year, 6 inches of water will suffice, or in Minnesota 10 inches are applied.

Recovery of investment presents a greater problem. Vernon Eidman of the University of Minnesota commented that the major hindrance to the spread of irrigation in Minnesota is the recovery of capital costs, not energy costs.[2] Larry Curtis of Alabama also notes that there has been a slowdown because of investment cost and tight money.[3] Tight money will probably ease but the high cost of investment will not, especially where

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[1] Personal communication with Wesley Musser, University of Georgia, Agricultural Economics Department, August 8, 1980.

[2] Personal communication with Vernon Eidman, University of Minnesota, Agricultural Economics Department, June 13, 1980.

[3] Personal communication with Larry Curtis, Auburn University, Agricultural Engineering Department, June 9, 1980.

Table 15. Type of Fuel Used for Irrigation in Several States in 1979

State	Expressed as a Percentage of All Power Units			
	Diesel	Electric	Gasoline	LPG
Minnesota	30	60	8	2
Wisconsin[1]	31	59	8	2
Michigan	32	41	24	3
Georgia	69	7	11	12
South Carolina	70	25	5	--
Alabama	77	7	9	7
Florida[2]	57	20	10	13

[1] 1977 data.

[2] Data for entire state.

Sources: Same as table 9, except: Wisconsin - same as table 13; Florida - Irrigation Journal, Volume 29, No. 6, December 1979.

expensive wells must be dug. Indeed, the cost of developing a source of water often is the factor that decides whether irrigation will be economically viable. As table 15 demonstrates, wells were the major source of irrigation water in Minnesota, Wisconsin, and northwest Florida. Moreover, the Dougherty Plain in southwest Georgia, the state's fastest growing area for irrigation, also relies on wells.

Table 17 for Georgia indicates the high proportion fixed costs play in these returns. A crucial factor is the source of water chosen or required. In the Dougherty Plain, an irrigated region of Georgia, the aquifer is covered by a limestone formation. By simply drilling a hole through this layer an artesian well will be produced (the pressure is not sufficient to force water to the surface). There is no need for the sand and gravel casing required by other wells. Well costs can vary by over $34,000 and irrigated expansion has been favored in this area because of the inexpensive wells. The presence of this limstone aquifer under several counties in South Carolina encourages irrigation in those areas too.

Michigan, Alabama, and most of Georgia use surface water as the major source for their irrigation (table 16). With surface systems, most farmers draw from on-farm pools or reservoirs. A general rule of thumb is that a pond should have 1 to 1-1/2 acre feet of water for every acre to be irrigated. If there is continuously flowing water into the pond, then a smaller capacity is sufficient. Development of surface water sources costs 25 percent as much as development of the sand and gravel wells (table 17). Surface water law in the East is primarily riparian and limits expansion of this type of irrigation to those whose land is contiguous to the stream. This is in contrast to the western water law of

Table 16. Source of Water for Irrigation in Several States

State	Expressed as a Percentage of All Water Sources			
	Groundwater	Surface Water	(Stream)*	(Pond & Reservoirs)*
Minnesota	90	10	--	--
Wisconsin[1]	63	37	(4)	(33)
Michigan	38	62	--	--
Georgia	31	69	(10)	(59)
South Carolina	n/a	n/a	n/a	n/a
Albama	25	75	(32)	(43)
Florida[2]	75	25	--	--

*Numbers in parentheses are subcategories of surface water sources.

[1] 1977 data.

[2] Data for entire state.

Sources: Same as table 9 except for: Minnesota - conversation with Roger E. Machmeier, Extension Agricultural Engineer, University of Minnesota; Wisconsin - same as table 13: Florida - Estimated Water Use in Florida, 1977, USGS Water Resources-Investigation 74-112, 1980.

Table 17. Costs of Center Pivot Irrigation for Single and Double Cropping Systems Using Alternative Water Sources in Georgia in 1980

Water Source	Cropping System	Irrigation Costs/Crop/Acre		
		Fixed	Operating	Total
Open hole well	Single	61.10 (4.68)*	24.80	85.90
	Double	30.55	24.80	53.35
Gravel packed well	Single	87.62 (31.20)*	24.80	112.42
	Double	43.81	24.80	68.61
Pond, Reservoir, Stream	Single	64.22 (7.80)*	24.80	89.02
	Double	32.11	24.80	56.91

*Numbers in parentheses are fixed costs attributable to developing the water source.

Source: Adapted from R. E. Brown and R. E. Skinner, Economic Analysis of Selected Sprinkler Irrigation Systems, Bulletin 731, Cooperative Extension Service, University of Georgia, March 1980, 23 pp.

Irrigation costs for a center pivot system that has: 150 acre coverage, 1000 GPM capacity and 120 H.P. diesel power unit. Water sources cost $6,000, $40,000, and $10,000 for the open well in limestone, gravel packed, and development of stream, pond, or reservoir, respectively. Fixed costs include depreciation, interest on average investment (12%), taxes (1%), and insurance (.4%).

Operating costs were developed using diesel fuel ($1.10/gal) with five applications (1 acre-inch/application) per season.

prior appropriation where water can be applied to any land regardless of location, so long as its use is "beneficial."

To overcome the problems of high investment costs, farmers are generally using three tactics. First, some are shifting to high-valued crops. Others, in areas with long growing seasons, are considering double and triple cropping. Finally, some are employing smaller, more portable systems that can be used on several fields at the same time.

Multiple cropping offers a significant way in the Southeast to reduce irrigation costs by reducing fixed costs. Table 17 illustrates the value of multiple cropping in Georgia with center pivot irrigation using different water sources. Water costs per acre for the gravel packed well can be reduced by approximately 38 percent by growing another crop. Unfortunately, double cropping is limited to areas where the growing season is long enough. This excludes the Lake States and South Carolina.[1] Though South Carolina is in the Southeast, it is too far north to support any double cropping system other than wheat and soybeans. But in southern Georgia, Alabama, and Florida there is greater potential, especially if farmers save time between harvest of the first crop and planting the second by moving to conservation tillage.

Recognizing this potential for double cropping in the region, the Richard K. Mellon Charitable Trust and the State of Georgia funded a research project near Tifton, Georgia to study "Irrigated Multiple-Cropping

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[1] Quisenberry, Clemson University, Agronomy Department, June 16, 1980.

Production Systems" in 1977.[1] The project is expanding its work to encompass many aspects of irrigation relating to the Southeast, including the application of fertilizers and pesticides through irrigation systems. Several multiple cropping systems and their returns to risk and management are listed in table 18. When double cropping corn for grain, the second crop was not profitable. In the corn silage sequence, the second crop was profitable. However, Tew noted that the market for silage is quite limited and a large crop would seriously depress prices and lower returns.[2] The second crop of grain sorghum after corn also showed positive returns. These results are very tentative, however, and data over more years would give a better indication of the possibilities. Other cropping systems being studied are corn-soybeans, corn-edible legumes, squash-soybeans, peanuts-small grains, and sweet corn-soybeans-small grains. One problem in growing vegetables is that there is a limited market in Georgia, and costs of transport elsewhere rise rapidly with distance.

Table 19 lists irrigation costs in Alabama in 1980. As in Georgia, the fixed costs are greater than the operating costs. This table illustrates two other ways of decreasing fixed costs per acre besides double cropping. The first is using large systems. In comparable systems, fixed costs decrease as the system size increases. The fixed costs per acre decrease from $110.25 with a 40-acre center pivot to $41.01 with a 210-acre center pivot. Likewise they decrease with cable tow utilizing one gun. One other possibility involves using a smaller system on several fields

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[1] Bonnie Riechert. "Irrigation Research in Georgia," Georgia Agricultural Research 20(3): Winter, 1979, pp. 10-12.

[2] Bernard Tew, Note Source for table 18 .

Table 18. Returns to Risk and Management for Several Double Cropping Systems in Tifton, Georgia in 1978.

Double Cropping System	First Crop	Second Crop	Total System
Corn for Grain[1]	97.36		
Corn for Grain		-44.77	52.60
Corn Silage[1]	167.35		
Corn Silage		61.03	228.38
Corn for Grain[1]	167.56		
Sorghum for Grain		24.17	192.72

Source: Bernard Tew and others. Costs and Returns of Irrigated Multiple-Crop Production of Corn Grain, Grain Sorghum and Corn Silage in the Georgia Coastal Plains, Faculty Series, Division of Agricultural Economics, University of Georgia.

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[1] Represent average returns from two different types of minimum tillage systems (rip-hip and rip-plant) from Table 1, pg. 7 of Tew.

[2] Represents average returns from chisel-plow and rip-plant tillage.

Table 19. Costs of Various Irrigation Systems Using a Surface Water Source in Alabama in 1980.

	Irrigation Cost/Crop/Acre		
	Fixed	Operating	Total
40 Acre Center Pivot	110.25	23.50	133.75
40 Acre Center Pivot (3 Pivot Points)	43.75	23.70	67.45
100 Acre Center Pivot	63.16	24.75	87.91
135 Acre Center Pivot	57.04	26.00	83.04
210 Acre Center Pivot	41.01	23.95	64.96
100 Acre Cable Tow (1 gun)	48.03	27.45	75.48
200 Acre Cable Tow (1 gun)	32.68	27.15	59.83
200 Acre Cable Tow (2 guns)	47.24	27.55	74.79
100 Acre Hose Tow (1 gun)	56.97	31.65	88.62

Source: J. L. Boutwell and L. M. Curtis, Irrigation System Cost Analysis, Summary Sheet-1980, Bulletin EE80-10, Alabama Cooperative Extension Service, Auburn University, 1980.

Water for all irrigation systems supplied from surface water source (pond, stream, or reservoir). Fixed costs include depreciation, interest on average investment (10%), and insurance on average investment (.7%)

Operating costs were developed using diesel fuel ($1.05/gal.) with five applications (1 acre-inch/application) per season.

concurrently. The fixed costs are reduced from $110.25 to $43.75 if the center pivot is rotated to two additional pivots. However, the farmer in incurs an additional labor cost in having to move the system from pivot point to pivot point. Also, limiting the time the system is operating on on each field will limit the amount of water it can apply to each. In the Southeast, where property lines, streams, and other obstacles limit field size, and rates of water application are low, these systems have real value. Larry Curtis indicates that increased emphasis is being placed on developing smaller, towable systems for the small fields of the Southeast.[1]

Finally, to increase returns many farmers are going to higher-valued crops. This is particularly true in the Lake State where, according to Vernon Eidman,[2] farmers are going to high-valued crops such as sweet corn, corn for seed, or other vegetables. The vegetable markets in the Lake States are more developed than in the Southeast (Florida excluded).

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[1] Larry M. Curtis. Irrigation in the 80's. Agricultural Engineering Series SWP 1-4, Alabama Cooperative Extension Service, Auburn University, Alabama, 1979.

[2] Personal communication with Vernon Eidman, June 13, 1980.

FUTURE GROWTH OF EASTERN IRRIGATION

POTENTIAL ACREAGE

The Second National Water Assessment by the U.S. Water Resource Council gives a projection for growth of irrigation acreage in the East.[1] It estimates that irrigated agriculture will grow from 5.7 million acres in 1975 to 8.2 million in 2000, averaging 1.5 percent annual growth rate (table 20). These projections are far below the irrigated acreage estimate of 10.3 million by the NRI for 1977. The Inter-Agency Task Force on Irrigation Efficiencies estimates that there were 8.3 million acres irrigated in 1977, also below the NRI estimate.[2] Clearly the Assessment and the Task Force underestimate the actual irrigated acreage in the East. In our judgment the Assessment's estimate of future growth--2.5 million acres from 1975 to 2000--also is low. However, the estimates were made in 1972-1974, before major recent increases in irrigated acreage in the East. While low, the estimates do indicate areas of important future growth. In particular the South Atlantic-Gulf is marked for additional expansion, mostly in Florida and southwest Georgia. The subregions in the Great Lakes and Upper Mississippi for which relatively high growth is expected are in the sandy areas in central Minnesota, central Wisconsin, eastern Michigan, and northern Indiana. Only a small amount of irrigated acreage is projected for the Corn Belt region, supporting the hypothesis that the soil is essentially too high-yielding under dryland

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[1] The Nation's Water Resources, 1975-2000, 1978.

[2] 1977 Task Force, Irrigation Water Use, p. 107.

Table 20. State and Regional Future (SRF) projections of Irrigated Acreage in the Eight Eastern Water Resource Regions in "1975," 1985, and 2000

Water Resource Regions	Irrigated farmland (1000 acres)		
	"1975"	1985	2000
New England	43	48	57
Mid-Atlantic	297	418	563
South Atlantic-Gulf	2,371	3,020	3,644
Great Lakes	164	243	334
Ohio	57	76	102
Tennessee	5	10	10
Upper Mississippi	244	523	638
Lower Mississippi	2,481	2,632	2,817
Total East	5,662	6,970	8,165

Source: U.S. Water Resources Council, Second National Water Assessment, Vol. 3, Appendix 1, Table 1-4, SRF estimates, p. 59.

Note: "1975" is a base year for assessment information. It represents an estimate of what acreage would be under "average" year climatic conditions, not of what actual acreage was in 1975.

conditions for irrigation to make a difference. The Assessment also indicates the relative importance of irrigation in the subregions containing the Delmarva Peninsula and New Jersey.[1] This would not be unexpected, given the sandy properties of those soils. Except for the irrigated acreage projected for the mid-Atlantic seaboard which we excluded in our analysis, the Assessment estimates of expansion potential by region are consistent with our observations.

The 1977 Task Force suggests that 26.2 million acres is the upper limit for irrigation in the East (including the Delta). This includes 24 million acres that could be irrigated on existing farmland, and 2.2 million that could be converted from other uses. Unfortunately for our purposes, the Task Force does not allocate this potential acreage by region within the East. However, the study by May, Shulstad and Erstine of irrigation in the Mississippi Delta indicates that there are 17 million acres with potential for irrigation in that region. If this is correct, the Task Force's estimate of 26.2 million acres for the East as a whole would imply about 9 million potential acres in regions of the East other than the Delta. The NRI shows 6.3 million irrigated acres in these regions in 1977 (table 1). This suggests that there is roughly an additional 3 million acres in these regions with potential for irrigation, most of it in the Southeast and the Lake States. The NRI indicates that in 1977 there were 58.3 million acres of cropland in the Southeast and Lake States with an additional 24.5 million acres with high-to-medium potential for conversion to cropland. These figures suggest that even if all the land in these regions with potential for irrigation were irrigated, the contribution of irrigation to total production of the crops of interest in this study would be small.

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[1] U.S. Water Resources Council, Second National Water Assessment, vol. 3, appendix 1, table 1-4, SRF estimates, pp. 61, 63.

In our judgment corn and soybeans will be the major irrigated crops in the East. Irrigated wheat will also grow in importance, especially where it can be double cropped with soybeans. Its acreage, however, will still remain substantially smaller than that of irrigated corn or soybeans. Cotton will not be a major irrigated crop because of numerous pest problems. Sorghum is a very minor crop at present and will probably remain so in the future.

ENVIRONMENTAL PROBLEMS

The Task Force report predicts that the growth of irrigation in the Southeast will lead to declines in groundwater levels and more reliance on surface water sources.[1] The principal artesian aquifer of the southeastern United States underlies most of Georgia and Florida, and small parts of South Carolina and Alabama. This aquifer is one of the major sources of groundwater in the country. The aquifer is of limestone and is rechargeable, with an estimated annual yield of water of 24 billion gallons a day[2] (measured as the base flow of streams). Over 3 billion gallons were pumped daily for agricultural, industrial, and municipal uses in 1978. While this usage is only slightly more than 10 percent of the yield, there are isolated regions of water table drawdown. In particular, drawdowns associated with irrigation have been charted in southwest Georgia. While these drawdowns are largely seasonal in nature (the aquifer is recharged over the winter months) geologists have noted a general downward trend in the groundwater level. There is concern that with increased pumping and a few dry years the water level of the aquifer would be lowered sufficiently to cause a reduction in surface flow.

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[1] 1977 Task Force, Irrigation Water Use, p. 113.

[2] Joseph T. Callahan, The Yield of Sedimentary Aquifers of the Coastal Plain Southeast River Basins, Geological Survey Water-Supply Paper 1669-W, 1964.

While this prospect is cause for concern, the primary environmental problem resulting from increased irrigation in southwest Georgia and the Southeast in general more likely will be water quality from irrigation return flows. The Second Assessment notes that there also are problems of irrigation return flows polluting surface water in southeastern Minnesota and southwestern Wisconsin, which have caused high chemical and bacterial concentrations in the Mississippi River below Minneapolis. The Assessment also notes erosion problems associated with agriculture in southwest Georgia. The expansion of irrigated agriculture in this area generally requires bringing marginal land into production. That is, while major clearing of forests is not occurring, on many fields there is considerable clearing to accommodate various sprinkler designs. Woods and grassy areas which normally retard erosion are being removed. Given the rapid expansion of irrigation in this region, the already serious erosion problem will probably be accelerated. This increased erosion will further accentuate the problem noted in the Assessment of bay and estuary degradation around the mouth of the Apalachicola River. This river carries dissolved solids and sediment from the agricultural land in southwest Georgia and Alabama.[1]

This paper has given major emphasis to the importance of sandy soils in the spread of irrigation. However, one problem with these soils is that pesticides and fertilizers are easily leached through the soil, polluting the groundwater. In the case of an aquifer formation with a limestone formation, much of the return flow will percolate down to the foundation and then move laterally to join the streamflow.

In most cases, the major pollutants are nitrates. Sandy soils tend to be very infertile; consequently more nitrogen is applied, resulting in more fertilizer runoff or deep percolation to the groundwater. In the sandhills of Nebraska, nitrate pollution of the groundwater has occurred. Almost double the national standards for nitrate concentration in drinking water are found in heavily irrigated areas of the state (20 ppm as compared to 10 ppm). Researchers in that area note that even with good management techniques it may not be possible over the long run to keep nitrate concentration to much less than 25 ppm.[2] While comparable studies have not been made, to our knowledge, in the Southeast, expansion of irrigation on the sandy soils of that region and the associated increase in application of nitrogen fertilizer may in time lead to a buildup in nitrate levels in ground and surface waters similar to what apparently has occurred in Nebraska.

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[1] The prospective erosion problem in Georgia is discussed in more detail in the study by Crosson and Brubaker of environmental impacts of agriculture in the United States.

[2] Personal communication with Darryl Watts, University of Nebraska, Agricultural Engineering Department, July 15, 1980.

Finally, mention is made in the Task Force report that the expansion of irrigation in many of the tidewater areas of the Delta and the Southeast would involve drainage of wetland and cutting of hardwood forests over sizeable areas. The Task Force projects a possible problem of maintaining a suitable habitat for wildlife and marine life under these circumstances.

"THE ECONOMIC POTENTIAL FOR THE EXPANSION OF IRRIGATION IN THE MISSISSIPPI DELTA REGION"

Final Report to

Resources For the Future

Performance Period

January 1, 1979 - June 30, 1980

Dr. Robert M. Shulstad Co-Principal Investigator	Dr. Ralph May Co-Principal Investigator
Billy E. Herrington Research Associate	Jon M. Erstine Graduate Research Assistant

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CHAPTER 1

INTRODUCTION

The objective of this study is to determine the potential for irrigation in the Mississippi Delta Region. That is, how many acres of a particular land and soil group can be economically irrigated assuming alternative types of irrigation systems, production costs, product prices, and levels of management. This information will be useful in predicting the contribution that the Mississippi Delta Region will make toward meeting the increase in demand for agricultural products, as well as provide base data from which to predict the environmental and resource implication of irrigation expansion.

THE RATIONALE FOR IRRIGATION EXPANSION

Why should producers in a region that receives what many would term ample precipitation even consider supplemental irrigation? For example, the six county sample area averages 49.25 inches of precipitation per year. The problem is that this precipitation is often not distributed in a manner adequate for high crop yields. The three most critical months for crop development in the area are usually June, July, and August. At this time most crops are in a stage where their moisture needs are highest. Unfortunately, these three months are generally among the dryest and hottest of the year with precipitation averaging 10.3 inches, or about .11 inches/day average, and maximum temperatures near the 90 to 100 degree range. In one year out of ten the area will receive less than 2.5 inches of moisture, or .027 inches/day average over this three month period. Evapotranspiration rates during this time can approach .33 inches/day so there is potential for deficient soil moisture conditions. In this situation yields will be adversely affected. In addition, the precipitation that does occur is ususally in the form of thundershowers during these months. These thundershowers tend to be erratic and undependable, with some producers receiving beneficial amounts of moisture and adjacent producers receiving little or none.

Irrigation, in addition to increasing yields in most years, may also help stabilize yields by eliminating lack of moisture as a variable. Stabilizing yields allows a producer to better estimate returns in advance because it narrows the range of yield possibilities. Irrigation also serves as an insurance factor. As the costs of producing a crop have continued to rise, the financial consequences of a poor crop or of crop failure have become much more severe. This is especially true for farmers who must borrow large amounts of operating capital to finance a crop.

Two changes in cropping patterns have occurred since the early 1970's in the area and both may serve to make irrigation more attractive. When the rice allotment program was in effect Arkansas planted 534,000 acres of rice in 1973. When the acreage restrictions were removed the acreage increased to slightly more than 1,000,000 acres in recent years. Mississippi had a similar experience, though on a smaller scale. With this increase in rice acreage many farmers are in a good position to irrigate soybeans rotated with rice. This practice depends upon an adequate water supply but this is not usually a problem in the region.

The other change in cropping patterns concerns double cropping wheat with soybeans. Many producers feel that the high cost of land necessitates some degree of year round production. As a result, wheat acreage in Arkansas has increased from 305,000 acres in 1973 to approximately 800,000 acres in recent years. The greatest risk in this type of rotation is that soybeans, planted late in the season due to wheat harvest, will not receive enough moisture to develop a strong stand. Some types of irrigation give the producer the option of "watering up" the soybeans if sufficient rainfall does not occur after planting.

Center pivot irrigation systems are becoming more prominent in the region. Furrow or flood irrigation cannot be practically used on soils that are gently undulating or have simple slopes of more than one percent. These soils comprise 12.2 percent of the region's cropland. Prior to the use of center pivot systems this land had to be land formed to an acceptable grade in order to irrigate. With center pivot irrigation this step is not necessary, although in some cases it may be more profitable to land form, use surface irrigation, and go into a rice rotation. Many producers choose to use center pivot systems even though they have land that could be furrow or flood irrigated. They are willing to accept the relatively higher costs of center pivot systems in return for the minimal labor requirements.

DESCRIPTION AND COMPARISON OF IRRIGATION METHODS USED IN STUDY

The technology of irrigation for agriculture is rapidly changing. Farmers are demanding labor-saving systems that are efficient, functional, and reasonably priced. The three irrigation systems examined include flood irrigation, furrow irrigation, and center pivot sprinkler irrigation.

Not all practices can be used on all farms because of differences in soil type, slope of land, and general outlay of fields.

Descriptions of the following irrigation systems were taken in part from a book entitled "Irrigation" by Warren Harris of the Agricultural Engineering Department of the University of Arkansas.

Flood Irrigation

Irrigation by the flood method (sometimes called contour-levee irrigation) requires that water be applied to nearly level field segments at a rate enough in excess of the intake rate of the soil to permit rapid coverage. The water is held by levees that surround the segments and are constructed longitudinally on the contour. Water is kept on the segments until the desired amount has been absorbed by the soil. The excess is then drained off by gravity and used on a similar segment at a lower elevation. The flood irrigation method has been used for many years for flooding rice fields. It has also been adapted to irrigate hay crops, small grains, and some row crops. If contour levees are used for irrigating row crops, the slope in the direction of the row drainage becomes a limiting factor. The maximum slope is that which will not result in erosion from storm runoff. The slope should also not be so great that a majority of the crop to be irrigated must be plowed up during construction of the levees. The minimum slope is that which will provide adequate drainage. In the study area levees in row crops are usually constructed only after the last cultivation has been done. If irrigation is required prior to the last cultivation the levees will be constructed, land irrigated, levees torn down, land cultivated and levees replaced if additional irrigation is required.

Furrow Irrigation with Gated-Pipe

Gated-pipe refers to a thin-walled, low pressure aluminum, plastic or rubber pipe with gates inserted at different spacings to match row width. The gates distribute the water along the ridge of the field to be surface irrigated. This system operates on low pressure with low fuel and horsepower requirements. Gated-pip commonly comes in sizes of 6, 8, 10, and 12 inches in diameter. The rate of flow from the water source will be used to determine the appropriate size of pipe. Furrow irrigation with gated pipe requires the use of hand labor. The amount of labor varies from farm to farm depending on field layout and accessability. Labor is required to load, lay, and move the pipe, check the gates, and check the furrows to see if the water has reached the prescribed destination.

Furrow irrigation is a gravity flow operation. Row grades range from .1 to .5 percent slope on the irrigated fields. Slopes flatter than this result in poor drainage. The length of run will vary from 600 feet up to ¼ mile in some cases. 1320 feet is the recommended maximum length of run for efficient irrigation.

Center-Pivot Sprinkler Irrigation

In the sprinkler method of irrigation, water is applied above the ground surface as a spray somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small nozzles. With careful selection of nozzle sizes, operating pressure, and sprinkler spacing, water can be applied uniformly at a rate based on the intake rate of the soil, thereby preventing runoff and resulting damage to land and crops. The sprinkler method is adaptable to irrigate most crops. The flexibility of present-day sprinkler equipment and its efficient control of application make this method adaptable to most topographic conditions without extensive land preparation.

The required capactiy of the sprinkler system depends on the size of the irrigated area, the depth of water to be applied at each irrigation and the time allowed to apply this amount of water.

Initial cost and power requirements for a center-pivot irrigation system are high in relation to the other systems because the center pivot system is operated under a higher pressure requiring additional horsepower over that used for flood or furrow irrigation.

The major advantage of center pivot irrigation is the adaptability to different land contours. Furrow and flood irrigation require a certain amount of land preparation before they are considered applicable. Center pivot irrigation makes it possible to irrigate that land that is typed as gently undulating, or having a slope too steep to flood or furrow irrigate.

The remainder of the thesis is organized into four chapters. Chapter two entails the methodology used to derive conclusions in the thesis. Chapter three discusses the cost/benefit ratios for alternate irrigated crop rotations under the twenty-four assumed situations. The potential increases in irrigated acreage are presented in Chapter four. Chapter five includes the summary and implications of the study.

CHAPTER 2

METHODOLOGY

A cost/benefit ratio must be favorable before the producer is willing to invest in irrigation. In this study the cost/benefit ratio is used as the best choice indicator of deciding on an irrigation system for a particular area. In the following chapter the cost/benefit ratios are compared for all alternative irrigation systems assuming alternative product prices, input costs, and management levels.

To estimate the cost/benefit ratio several factors are considered. Input and output quantities are determined for each irrigation system, crop and soil type. Irrigation equipment catalogs, personal interviews with irrigation well drillers, and the 1980 Arkansas crop budgets provide the base data for input use and input prices. Yields for dry land and irrigated production practices were obtained from personal interviews with farmers in the study area, Arkansas Experiment Station agronomist, and the Arkansas Soisl Guide Form V.

Projections of irrigation feasibility are based on 1985 prices converted to 1980 dollars. The 1985 prices reflect baseline and high demand situations as estimated by the U.S.D.A. GOL model. The following assumptions apply to the study:

1) Rotational crop production is assumed. The rotations are (a) rice - soybeans - soybeans, (b) rice - soybeans/wheat (double cropped) - soybeans, (c) soybeans- soybeans/wheat (double cropped), (d) cotton - soybeans, (e) grain-sorghum - soybeans, (f) corn - soybeans. It is recognized that not all rotations are feasible on every soil group.

2) The majority of irrigation expansion will come from the top 10 percent of managers. The yields used in this study reflect this high level of management. For comparison, the analysis is also performed using yields based on average management.

3) Irrigation systems are designed to irrigate 160 acres or what is possible in the case of the center pivot sprinkler irrigation system. Wells and power units are designed to match the irrigation system requirements. Specifications and assumptions for the four wells used in the study are outlined in Table 2-1.

4) Rice is grown under flood irrigation conditions in all situations.

TABLE 2-1

SPECIFICATIONS AND ASSUMPTIONS FOR ELECTRIC AND DIESEL IRRIGATION WELLS

Well "A" Electric

1) Well is 100 feet deep with an 8 inch turbine pump including 2 stages of 12 inch bowl.

2) Well pumps 800 g.p.m.

3) Total dynamic head is 80 feet, and the lift is 50 feet.

4) Depreciate well and casing using 40 years straight line method with 0 percent salvage value.

5) Depreciate pump using 15 years straight line method with 0 percent salvage value.

6) Depreciate motor using 35 years straight line method with 0 percent salvage value.

7) Compute interest on average investment at rate of 10 percent.

8) Compute taxes at (0.01/dollar of value).

9) Compute insurance cost at ($.006/dollar of average investment insured).

10) Compute rate per kw/hr at .053 times annual kw usage.

Replacement Costs of Components of Well "A" Electric

1)	Drilling, casing and installation	4300.00
2)	Pump Assembly	4200.00
3)	50 H.P. Electric motor, fuses, starter box	2575.00
4)	50 H.P. gear drive	1100.00
	Total Cost	12175.00

Annual Ownership Cost:

1)	Depreciation (new cost/n)	535.83
2)	Interest [(new cost/2) Interest	608.75
3)	Taxes [new cost x .01]	121.75
4)	Insurance	47.25
	Annual Ownership Cost	1313.58

Well "A" Diesel

1) Well is 100 feet deep with an 8 inch turbine pump including 2 stages of 12 inch bowl.

2) Well pumps 800 g.p.m.

3) Total dynamic head is 80 feet, and the lift is 50 feet.

4) Depreciate well and casing 40 years straight line with 0 percent salvage value.

5) Depreciate pump 15 years straight line with 0 percent salvage value.

6) Depreciate power unit 15 years straight line with 0 percent salvage.

7) Compute interest on average investment at 10.00 percent.

8) Compute taxes at (.01/dollar of value).

9) Compute insurance cost at ($.006/dollar of average investment insured).

10) Compute cost of diesel at $.95 per gallon.

Replacement Cost of Components of Well "A" Diesel

1)	Drilling, casing, and installation	4300.00
2)	Pump Assembly	4200.00
3)	55 H.P. max, 44 H.P. continuous diesel engine	5266.00
4)	50 H.P. gear drive	1100.00
	Total Cost	14866.00

Annual Ownership Cost:

1)	Depreciation (new cost/n)	855.23
2)	Interest [(new cost/2)] Interest	743.30
3)	Taxes [new cost x .01]	148.66
4)	Insurance	63.39
	Total Annual Ownership Cost	1810.58

Well "B" Diesel (Used on center pivots)

1) Well is 100 feet deep with an 8 inch turbine pump including 4 stages of 12 inch bowl.

2) Well pumps 1000 g.p.m. at 90 p.s.i.

3) Total dynamic head is 259 feet, lift is 50 feet.

4) Depreciate well and casing 40 years straight line with 0 percent salvage value.

5) Depreciate pump 15 years straight line with 0 percent salvage value.

6) Depreciate power unit 15 years straight line with 0 percent salvage value.

7) Compute interest on investment at 10.00 percent.

8) Compute taxes at (.01/dollar of value).

9) Compute insurance cost at ($.006/dollar of average investment insured).

10) Compute cost of diesel at $.95 per gallon.

11) Depreciate center pivot 15 years straight line with 0 percent salvage value.

12) Center pivot, ¼ mile system cover 135 of 160 acres.

Replacement Cost of Components of Well "B" Diesel

1)	Drilling, casing, and installation	4400.00
2)	Pump assembly	6300.00
3)	110 H.P. max, 88 H.P. continuous diesel engine	7537.00
4)	100 H.P. gear drive	1500.00
5)	¼ mile center pivot	34000.00
	Total Cost	53737.00

Annual Ownership Cost:

1)	Depreciation (new cost/n)	3248.51
2)	Interest [(new cost/2)] Interest	2686.85
3)	Taxes [new cost x .01]	537.37
4)	Insurance	296.02
	Total Annual Ownership Cost	6768.75

Well "B" Electric (Used on center pivots)

1) Well is 100 feet deep with an 8 inch turbine pump including 4 stages of 12 inch bowl.

2) Well pumps 1000 g.p.m. at 90 p.s.i.

3) Total dynamic head is 259 feet, lift is 50 feet.

4) Depreciate well and casing 40 years straight line with 0 percent salvage value.

5) Depreciate pump 15 years straight line with 0 percent salvage value.

6) Depreciate motor 35 years straight line with 0 percent salvage value.

7) Compute interest on investment at 10.00 percent.

8) Compute taxes at (.01/dollar of value).

9) Compute insurance cost at $.006/dollar of average investment insured).

10) Compute rate per kw/hr at .053 times annual kw usage.

11) Depreciate center pivot 15 years straight line with 0 percent salvage value.

12) Center pivot, ¼ mile system cover 135 of 160 acres.

Replacement Cost of Components of Well "B" Electric

1)	Drilling, casing, and installation	4400.00
2)	Pump assembly	6300.00
3)	100 H.P. electric motor, fuses, starter box	4337.00
4)	100 H.P. gear drive, flex shaft	1675.00
5)	¼ center pivot system	34000.00
	Total Cost	50712.00

Annual Ownership Cost:

1)	Depreciation (new cost/n)	2968.43
2)	Interest [(new cost/2)] Interest	2535.55
3)	Taxes [new cost x .01]	507.11
4)	Insurance	277.87
	Annual Ownership Cost	6288.96

DATA NEEDS AND SOURCES

The data needed to determine the potential for expansion of irrigation in the Mississippi Delta Region are:

1) The amount of cropland in the study area and the number of acres suitable for irrigation.

2) Production requirements and costs of crops used in the six rotations on a non-irrigated and irrigated basis.

3) Cost associated with irrigating cropland, i.e., -- cost of well, cost of power unit and accessories, cost of irrigation system itself, fuel costs, and annual ownership costs. All irrigation water is assumed to come from wells. This will tend to bias pumping costs upward since pumping of surface water is generally less expensive.

4) Two sets of crop prices; 1985 baseline crop prices, 1985 high demand crop prices are needed to measure the economic potential for increased irrigation. All prices are expressed in constant 1980 dollars.

5) A discount rate is needed to discount costs and returns back to year one. The rate, which because of the absence of any inflationary factor to represent a true discount rate,will be 10 percent.

THE STUDY AREA

Due to resource constraints, data were gathered from a six county area determined to be typical of the Mississippi Delta Region of Arkansas. The sample area and Delta region are shown in Figures 2-1 and 2-2, respectively. The counties surveyed were Chicot, Desha, Phillips, Crittenden, Mississippi and Clay. They range geographically from the southeast corner of the state to the extreme northeast corner of Arkansas. These counties were chosen because, when combined, they form a highly representative sample of the Delta region in terms of soil types, slopes, drainage, cropping patterns, farm organization, and climate. Arkansas County, which was included in previous

Mississippi Delta research, was not sampled because it is located on the Grand Prarie. This area is the major rice production section of Arkansas and has nearly fully utilized water resources. Consequently, little potential exists for further irrigation expansion in this area.

Soil mapping units in the sample area are grouped to form productivity groups which are relatively homogenous with regard to productivity and management. The major factors considered in forming the groups are permeability, surface texture, and slope. The soil groups are presented in Table 2-2.

TABLE 2-2
IDENTIFICATION OF SAMPLE AREA SOIL GROUPS

Identification Number	
1.	Slow permeability, loamy soil texture, 0-1 percent slope
2.	Slow permeability, loamy soil texture, 1-3 percent slope or gently undulating.
3.	Slow permeability, loamy soil texture, land formed slope.
4.	Slow permeability, clayey soil texture, 0-1 percent slope.
5.	Slow permeability, clayey soil texture, 1-3 percent slope or gently undulating.
6.	Slow permeability, clayey soil texture, land formed slope.
7.	Moderate permeability, loamy soil texture, 0-1 percent slope.
8.	Moderate permeability, loamy soil texture, 1-3 percent slope or gently undulating.
9.	Moderate permeability, loamy soil texture, land formed slope.

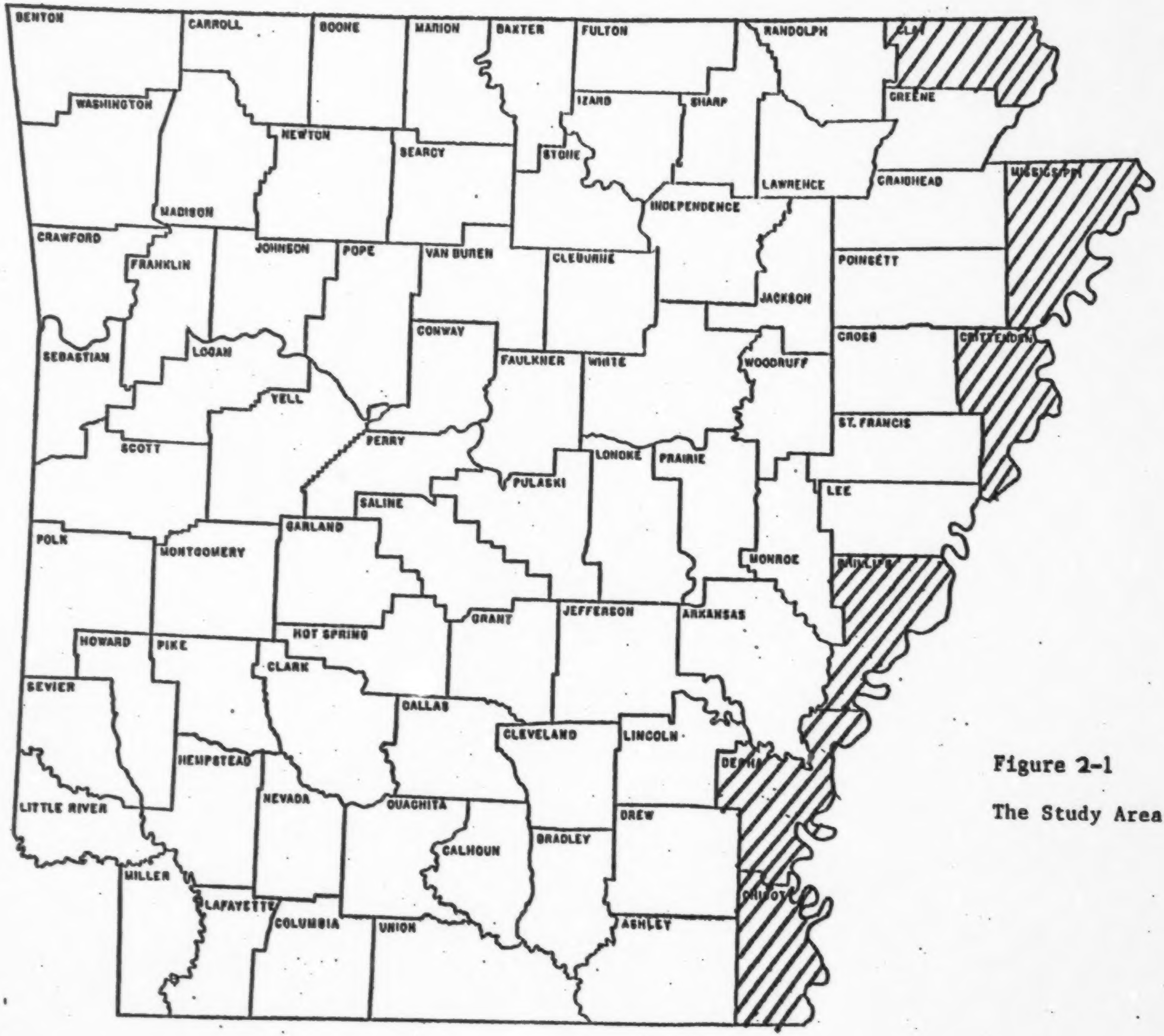
BENTON
CARROLL
BOONE
MARION
BAXTER
FULTON
RANDOLPH
CLAY
WASHINGTON
IZARD
SHARP
GREENE
NEWTON
SEARCY
STONE
LAWRENCE
CRAIGHEAD
MISSISSIPPI
MADISON
INDEPENDENCE
CRAWFORD
FRANKLIN
JOHNSON
POPE
VAN BUREN
CLEBURNE
POINSETT
JACKSON
SEBASTIAN
LOGAN
CONWAY
FAULKNER
WHITE
WOODRUFF
CROSS
CRITTENDEN
YELL
ST. FRANCIS
SCOTT
PERRY
LONOKE
PRAIRIE
PULASKI
SALINE
LEE
GARLAND
POLK
MONTGOMERY
MONROE
PHILLIPS
GRANT
JEFFERSON
ARKANSAS
HOWARD
PIKE
HOT SPRING
CLARK
SEVIER
DALLAS
CLEVELAND
LINCOLN
HEMPSTEAD
DESHA
NEVADA
OUACHITA
LITTLE RIVER
DREW
BRADLEY
CALHOUN
MILLER
CHICOT
LAFAYETTE
COLUMBIA
UNION
ASHLEY

Figure 2-1

The Study Area

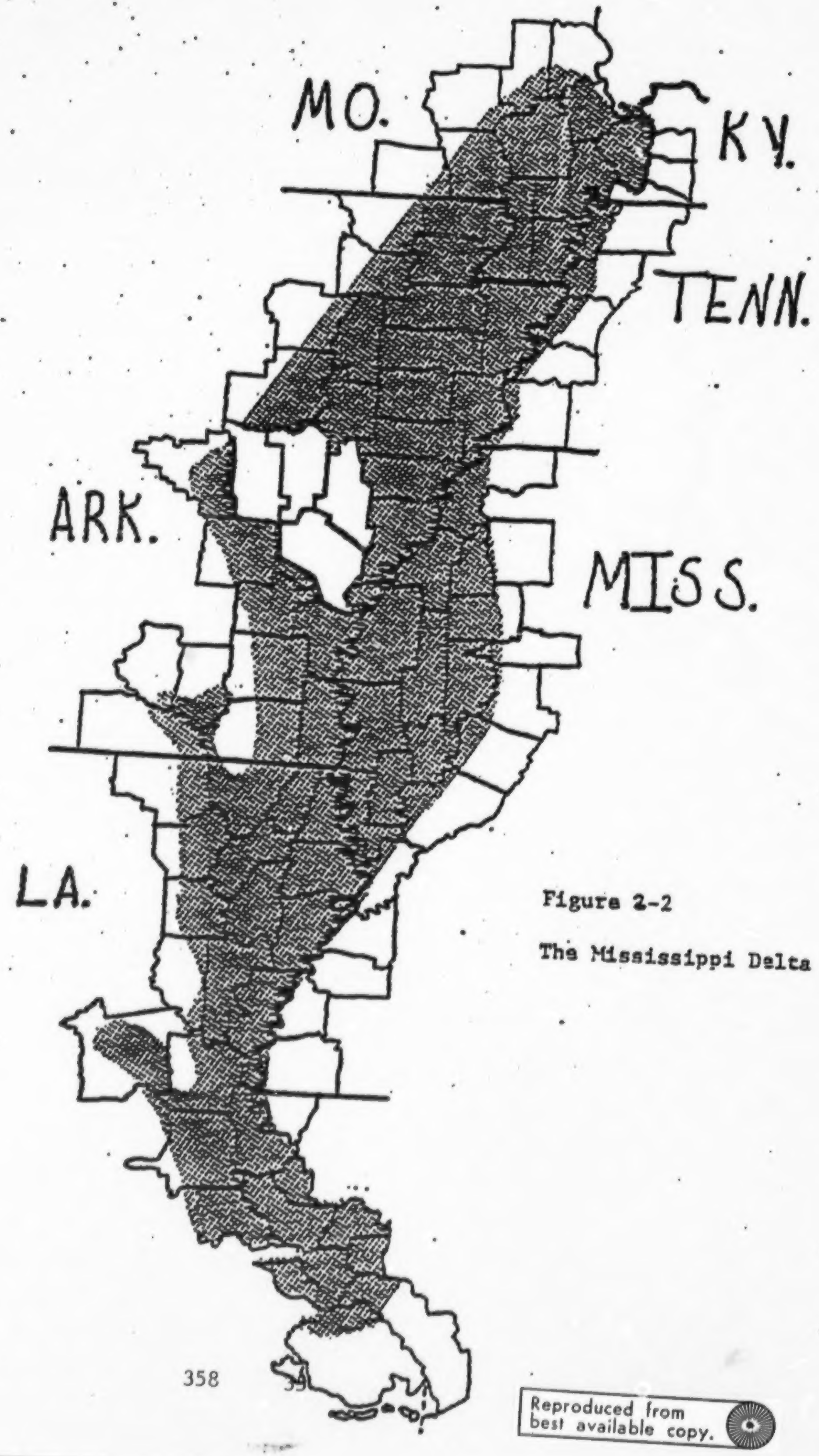
MO.
KY.
TENN.
ARK.
MISS.
LA.

Figure 2-2

The Mississippi Delta Region

Reproduced from best available copy.

Present land use and potential irrigated acreage available were obtained from both personal interviews with members of the County Soil Conservation Service and Cooperative Extension Service and the data bank identified as RIDS.

The RIDS system identifies land use for each square kilometer and soil mapping unit for each quarter kilometer. Information may be retrieved by mapping units and aggregated into productivity classes based on the characteristics believed most significant by the researcher. In order to utilize the RIDS estimates of land available by soil type, the following conversion technique was used to obtain estimated acreage.

"If a county has 450,000 acres (according to county soil map) and there are 200 observations, each observation is assumed to have a value of 2,250 acres. The number of observations in each land use category are totaled and multiplied by the acreage value of a single observation. In this manner the total acreage of each land use in each county is found. Since the data are also presented by soil mapping units it is possible to determine the acreage of specific soils present in each land use category."[1]

Land formed cropland is not identified in the RIDS survey so estimates by ASCS and SCS are used. Land forming is often refered to as "land leveling". This term is a misnomer since one objective of land forming is to intentionally create a predetermined slope. This slope varies according to the crops to be grown after land forming because a slope needed to hold water on rice properly is not necessarily the best slope for say, corn. The field is first surveyed to determine high and low areas in the field. The areas are then marked with staked flags of different colors to designate whether an area should be cut, filled, or left alone. Tandem dirt buckets are pulled behind large tractors to make the cuts and haul the soil to lower areas where it is dumped as smoothly as possible to roughly create the desired slope. When the dirt bucket work is finished a land plane is pulled over the field to smooth the soil to the final grade. Only 0-1% or gently undulating slopes are considered for land forming due to the extremely deep cuts and fills that would be required on steeper slopes.

---

[1] Billy Herrington, The Economic Feasibility of Increasing Crop Production in the Mississippi River Delta Region Through the Conversion of Non-Cropland to Cropland, and the Upgrading of Existing Cropland. Unpublished M.S. Thesis, University of Arkansas, Department of Agricultural Economics and Rural Sociology, 1979.

Land forming can also be used to eliminate old, meandering sloughs and ditches which run through the field. These areas are filled with soil from the high spots. The filling often results in an increase in the farmable land of 10%. The effects of slope creation and field consolidation are immense. Farmable acreage, drainage, and yields are improved as is the efficiency of time, labor, machinery, and chemicals. The farmer does pay a price for these benefits other than the initial cost of land forming, however. Yields of most crops, rice being the exception, are lowered in the years immediately following land forming due to soil compaction, cuts into the subsoil, and sponginess in filled areas. The recovery period ranges from zero to seven years depending upon the soil type.

NORMAL PER ACRE PRODUCTION COSTS

Dryland production cost per acre is obtained from the 1980 Arkansas crop budgets for non-irrigated production. Costs for each specific irrigation system are added to these budgets. The flood, furrow, and center pivot sprinkler irrigation system costs were based on irrigating 160 acres. Both diesel and electric power units are analyzed. Systems are designed to reflect typical wells and systems used in the study area.

Normal per acre production costs for non-irrigated, flood irrigated, furrow irrigated, and center pivot sprinkler irrigated crops are shown in Table 2-3.

Normal per acre production costs with a 33 percent increase in variable production cost are also derived in order to project near future costs. This was believed necessary because of the major increases that have occurred in variable cost in the past few years. These costs are shown in Table 2-4.

Irrigation costs are estimated for only four broad soil classes, non-land formed loam, non-land formed clay, land formed loam, and land formed clay soils. Thus irrigation is identical across some of the nine soil productivity classes.

The irrigated budgets are based on crop, irrigation system, power source, and soil class.

Soil groups two and four must be land formed before rice production is attempted on these soils.

Cotton was not considered on land formed land. Although many acres of traditional cotton land have been land formed much of it was done in the 1960's during the cotton acreage diversion program. Cotton on newly land formed land is not recommended.

TABLE 2-3

NORMAL PER ACRE PRODUCTION COST FOR NON-IRRIGATED CROPS

	Soils			
	Non-Land Formed		Land Formed	
Crop	Loam	Clay	Loam	Clay
Soybeans	118.86	110.91	123.43	114.26
Corn	146.28	NA	153.61	NA
Cotton	344.51	344.01	NA	NA
Grain Sorghum	155.57	155.57	164.20	164.20
Wheat	81.92	81.92	86.15	86.15
Double-Cropped Soybeans	200.78	192.83	209.58	200.41

NORMAL PER ACRE PRODUCTION COST FOR FLOOD IRRIGATED RICE

	Soils			
	Non-Land Formed		Land Formed	
Fuel Source	Loam	Clay	Loam	Clay
Electric	356.11	368.85	367.29	380.54
Diesel	390.95	389.69	399.45	413.04

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED SOYBEANS

		Soils			
		Non-Land Formed		Land Formed	
Irrigated Method	Fuel Type	Loam	Clay	Loam	Clay
Flood	Electric	151.05	NA	155.70	NA
Flood	Diesel	155.34	NA	159.99	NA
Furrow	Electric	155.48	147.98	160.17	151.44
Furrow	Diesel	157.52	150.06	161.59	153.53
Center Pivot	Electric	185.48	177.50	NA	NA
Center Pivot	Diesel	193.50	185.99	NA	NA

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED CORN

		Soils	
		Non-Land Formed	Land Formed
Irrigation Method	Fuel Type	Loam	Loam
Furrow	Electric	197.53	206.05
Furrow	Diesel	203.96	212.48
Center Pivot	Electric	227.42	NA
Center Pivot	Diesel	237.39	NA

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED COTTON

		Soils	
Irrigated Method	Fuel Type	Loam	Clay
Furrow	Electric	373.59	366.17
Furrow	Diesel	377.42	370.00
Center Pivot	Electric	413.93	406.99
Center Pivot	Diesel	422.00	415.07

NA - Flood irrigation applies only to rice, and soybeans grown on loam soils. Center pivot irrigation is not considered on land formed land. Corn is grown on loam soils only. Cotton is not grown on land that has been land formed. For a complete explanation of these assumptions see Chapter 1.

TABLE 2-4

NORMAL PER ACRE PRODUCTION COST FOR NON-IRRIGATED CROPS WITH A 33 PERCENT INCREASE IN VARIABLE COSTS

	Soils			
	Non-Land Formed		Land Formed	
Crop	Loam	Clay	Loam	Clay
Soybeans	145.37	134.10	151.45	138.56
Corn	181.16	NA	190.90	NA
Cotton	425.12	424.83	NA	NA
Grain Sorghum	193.50	193.50	204.96	204.96
Wheat	100.33	100.33	105.95	105.95
Double-Cropped Soybeans	245.70	234.44	257.41	244.52

NORMAL PER ACRE PRODUCTION COST FOR FLOOD IRRIGATED RICE WITH A 33 PERCENT INCREASE IN VARIABLE COST

	Soils			
	Non-Land Formed		Land Formed	
Fuel Type	Loam	Clay	Loam	Clay
Electric	443.70	485.09	458.57	473.64
Diesel	488.13	496.71	499.44	515.79

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED SOYBEANS WITH A 33 PERCENT INCREASE IN VARIABLE COST

		Soils			
		Non-Land Formed		Land Formed	
Irrigation Method	Fuel Type	Loam	Clay	Loam	Clay
Flood	Electric	183.36	NA	189.54	NA
Flood	Diesel	188.19	NA	194.37	NA
Furrow	Electric	188.82	178.16	195.06	182.76
Furrow	Diesel	191.11	180.50	196.53	185.12
Center Pivot	Electric	213.84	207.37	NA	NA
Center Pivot	Diesel	228.01	217.34	NA	NA

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED CORN WITH A 33 PERCENT INCREASE IN VARIABLE COST

		Soils	
		Non-Land Formed	Land Formed
Irrigation Method	Fuel Type	Loam	Loam
Furrow	Electric	243.93	255.26
Furrow	Diesel	251.57	262.91
Center Pivot	Electric	273.54	NA
Center Pivot	Diesel	285.61	NA

NORMAL PER ACRE PRODUCTION COST FOR IRRIGATED COTTON WITH A 33 PERCENT INCREASE IN VARIABLE COST

Irrigation Method	Fuel Type	Soils	
		Loam	Clay
Furrow	Electric	459.47	450.56
Furrow	Diesel	463.71	454.80
Center Pivot	Electric	501.86	493.59
Center Pivot	Diesel	510.97	503.01

NA - Flood irrigation applies only to rice, and soybeans grown on loam soils. Center pivot irrigation is not considered on land formed land. Corn is grown on loam soils only. Cotton is not grown on land that had been land formed. For a complete explanation of these assumptions see Chapter 1.

CROP PRICES

Two sets of crop prices are used with all prices expressed in constant 1980 dollars. The 1985 crop prices are derived from the U.S.D.A. Grain-Oilseeds and Livestock Model (GOL). Baseline conditions assume "world grain trade prices in real terms are likely to average closer to the low levels of 1969/70 - 1971/72 base period than the high levels of 1972/73 - 1974/75 period" and high demand conditions assume "real grain prices... would be substantially higher than in the base 1969/70 - 1971/72 period but still below the levels of 1972/73 - 1974/75."[2]

Only soybean meal, feed grain and wheat prices are projected in the GOL model. Thus soybean prices are estimated as a function of soybean meal prices and corn and grain sorghum as a function of feed grains. Projected rice prices are derived from projections developed for the world rice model[3] and cotton prices are adapted from projections published in Data Resources.[4] All sets of crop prices and sources may be found in Table 2-5.

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[2] Pierre Crosson, Unpublished memorandum, "Price Projections," Resources For The Future, Inc. (Washington, D.C., 1978).

TABLE 2-5

CROP PRICES IN 1980 REAL DOLLARS AND SOURCES

Price Model	Crop	Price	Source
1985 baseline prices	Soybeans	$6.60/bu	Resources For The Future, Inc., based on a function of soybean meal prices, U.S.D.A. GOL model
	Rice	$4.15/bu	Derived from World Rice Production Disappearance, and Trade 1960 Decade With Projections to 1980
	Cotton lint	$0.72/lb	The projected 1980 price of $0.52/lb from Data Resources was assumed to grow at the rate of 5% per year until 1985. This manipulation resulted in a 1985 price of $0.66/lb; $0.60 was assumed as a baseline price. These prices were used in a 1978 project. They were increased using the C.P.I. to 1980 levels. This increase resulted in a $0.72 baseline price, and a $0.82 high demand price.

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[3] Troy Mullins, et al., World Rice Production Dissappearance, and Trade 1960 Decade with Projections to 1980. Arkansas Agricultural Experiment Station, Bulletin 819 in cooperation with Economic Research Service, U.S.D.A.; (Fayetteville, Arkansas 1977).

[4] Data Resources, Inc., DRI Agriculture Service Quarterly Review, Volume 3, Number 4 (Lexington, Massassachusetts, Winter 1978).

TABLE 3-5

CROP PRICES IN 1980 REAL DOLLARS AND SOURCES (continued)

Price Model	Crop	Price	Source
1985 baseline prices	Cotton seed	$.059/lb	Based on a linear function of lint seed prices
	Corn	$3.02/bu	Based on a function of feed grain index, U.S.D.A. GOL model
	Wheat	$3.37/bu	Resources For The Future, Inc., based on J.S.D.A. GOL model
	Grain sorghum	$2.43/bu	Resources For The Future, Inc., based on a function of feed grain index, U.S.D.A. GOL model
1985 high demand prices	Soybeans	$7.48/bu	Resources For The Future, Inc., based on a function of soybean meal prices, U.S.D.A. GOL model
	Rice	$5.56/bu	Derived from *World Rice Production Disappearance, and Trade 1960 Decade With Projections to 1980*
	Cotton lint	$0.82/lb	Derived in same manner as 1985 baseline price, $0.82/lb assumed as high demand price, *Data Resources*
	Cotton seed	$.067/lb	Based on a linear function of lint and seed prices
	Corn	$3.50/bu	Based on a function of feed grain index, U.S.D.A. GOL model
	Wheat	$4.09/bu	Resources For The Future, Inc., based on U.S.D.A. GOL model
	Grain sorghum	$2.91/bu	Resources For The Future, Inc., based on a function of feed grain index, U.S.D.A. GOL model

OPPORTUNITY COST

The opportunity cost of irrigated cropland is represented by the yearly net returns from dryland crop production which would be foregone. Opportunity cost is estimated from the returns above specified costs received from non-irrigated crops as specified in the 1980 Arkansas crop budgets. When irrigation is analyzed, the highest crop use (based on lowest cost/benefit ratio) on dryland crops will serve as the crop for estimating opportunity cost. Opportunity costs will vary between "best" rotations, crop prices, soil groups, yield sets, and production costs.

BASE CROP YIELDS FOR TOP 10 PERCENT OF MANAGERS

The irrigated and non-irrigated crop yields for specific soils were derived from several sources. The per acre yields for rice, cotton lint, and soybeans came from S.C.S. Form V. They are weighted average for the specific soils found in each group.

Additional information had to be supplied by crop and soils experts to determine yields for double-cropped soybeans, cotton seed, grain sorghum, corn and wheat.

Flood and center pivot sprinkler systems do not allow irrigated production on 100 percent of a field. Levees must be constructed for flood irrigation and soybeans are plowed up in the process. This does not apply to rice irrigation under flooded conditions because rice is usually planted on the levees at the same time that the field is planted.

Yields for flood irrigated soybeans are assumed to be 10 percent below yield from furrow irrigated soybeans due to the construction of levees. In the case of center pivot sprinkler irrigation the corners of the field are not irrigated. In this study 135 acres are irrigated by the center pivot system with 25 acres remaining unirrigated. The yield of the 135 irrigated acres and the yield of the 25 non-irrigated acres are used to form a weighted average yield for the 160 acres.

Yields for land-formed land are increased by 10 percent above non-land-formed yields to reflect the additional cropland taken into production by land-forming. Additional increases in yields on land-formed land depend on the number of years following land forming, the soil type, and the improvement in drainage and irrigation efficiency. Base crop yields for non-irrigated and irrigated for the top 10 percent of managers are presented in Table 2-6.

TABLE 2-6

BASE CROP YIELDS
HIGH YIELD MANAGEMENT
NON-IRRIGATED

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Grain Sorghum (bu)	Corn (bu)
1	29	25	620	1240	58	73
2	26	22	612	1224	52	65
3	38	34	NA	NA	77	97
4	35	31	599	1198	61	NA
5	30	26	584	1168	53	NA
6	42	38	NA	NA	74	NA
7	37	33	733	1466	74	93
8	37	33	771	1542	74	93
9	48	44	NA	NA	96	120

NA - Non-Applicable for crop and soil group.

BASE CROP YIELDS
HIGH YIELD MANAGERS
FLOOD IRRIGATION

Soil Group	Rice (bu)	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Grain Sorghum (bu)	Corn (bu)
1	130	32	28	NA	NA	NA	NA
2	NA	NA	NA	NA	NA	NA	NA
3	143	39	35	NA	NA	NA	NA
4	126	NA	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA	NA	NA
6	139	NA	NA	NA	NA	NA	NA
7	NA	42	38	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA
9	NA	49	45	NA	NA	NA	NA

BASE CROP YIELDS
HIGH YIELD MANAGERS
FURROW IRRIGATION

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Corn (bu)
1	36	32	812	1624	132
2	NA	NA	NA	NA	NA
3	43	39	NA	NA	160
4	44	40	659	1318	NA
5	NA	NA	NA	NA	NA
6	48	44	NA	NA	NA
7	47	43	960	1920	120
8	NA	NA	NA	NA	NA
9	54	50	NA	NA	140

NA - Non-Applicable for crop and soil group.

BASE CROP YIELDS
HIGH YIELD MANAGERS
CENTER PIVOT IRRIGATION

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Corn (bu)
1	NA	NA	NA	NA	NA
2	32	32	772	1554	109
3	NA	NA	NA	NA	NA
4	NA	NA	NA	NA	NA
5	37	37	633	1226	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	45	45	973	1946	116
9	NA	NA	NA	NA	NA

NA - Non-Applicable for crop and soil group.

BASE CROP YIELDS FOR AVERAGE MANAGERS

Average crop yields for cotton, rice, and soybeans are from the Agricultural Statistics for Arkansas for 1974-1977. Yields for non-irrigated corn and grain sorghum are from the Statistical Reporting Service. These average yields are not defined by soil type because they are reported as county average yields without reference to soil type. To estimate the specific soil type crop yields, the four year average yields are divided by the average of the high crop yields used in the first part of the analysis. The resulting percentage is then multiplied by the specific soil type crop yield to derive an estimate of the average yields on particular soil groups.

Base crop yields non-irrigated and irrigated for average managers are presented in Table 2-7.

TABLE 2-7

BASE CROP YIELDS
AVERAGE MANAGERS
NON-IRRIGATED

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Grain Sorghum (bu)
1	19	15	415	830	49
2	17	13	410	820	44
3	26	22	NA	NA	65
4	23	19	401	802	51
5	20	16	391	782	45
6	30	26	NA	NA	62
7	25	21	491	982	62
8	25	21	517	1034	62
9	33	29	NA	NA	80

NA - Non-Applicable for crop and soil type.

BASE CROP YIELDS
FOR AVERAGE MANAGERS
FLOOD IRRIGATION

Soil Group	Rice (bu)	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)	Sorghum (bu)	Corn (bu)
1	103	26	22	NA	NA	NA	NA
2	NA	NA	NA	NA	NA	NA	NA
3	113	31	27	NA	NA	NA	NA
4	100	NA	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA	NA	NA
6	110	NA	NA	NA	NA	NA	NA
7	NA	34	30	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA
9	NA	39	35	NA	NA	NA	NA

BASE CROP YIELDS
AVERAGE MANAGERS
FURROW IRRIGATION

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)
1	29	25	544	1088
2	NA	NA	NA	NA
3	35	31	NA	NA
4	35	31	441	882
5	NA	NA	NA	NA
6	40	36	NA	NA
7	38	34	643	1286
8	NA	NA	NA	NA
9	44	40	NA	NA

NA - Non-Applicable for crop and soil type

BASE CROP YIELDS
AVERAGE MANAGERS
CENTER PIVOT IRRIGATION

Soil Group	Soybeans (bu)	Double-Cropped Soybeans (bu)	Cotton Lint (lbs)	Cotton Seed (lbs)
1	NA	NA	NA	NA
2	25	25	517	1034
3	NA	NA	NA	NA
4	NA	NA	NA	NA
5	28	28	424	848
6	NA	NA	NA	NA
7	NA	NA	NA	NA
8	36	36	652	1304
9	NA	NA	NA	NA

NA - Non-Applicable for crop and soil type

CHAPTER 3

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Cost/benefit ratios are compared to determine the rotation providing the highest rate of return on a given soil group under alternative situations. These situations take into account two different levels of crop prices, nine soil groups, two levels of crop yields, three irrigation methods using two different fuel types, six possible rotations, normal and increased variable production cost, and two levels of opportunity costs. The study of the cost/benefit ratio analysis entails twenty-four situations in all and will be compared at a discount rate of 10 percent.

It should be noted that certain assumptions are made in deriving the cost/benefit ratios with regards to rotations and irrigation types used on certain soil groups. In the case of rotations, not all rotations are assumed to be feasible on all soil groups. This assumption results from personal interviews with local farmers and agronomy and soil experts. It is again noted that this study was based on situations that are common in the study area.

TABLE 3-1

IDENTIFICATION OF ALTERNATIVE CROP PRICES, PRODUCTION COSTS, YIELD SITUATIONS, AND IRRIGATION SYSTEM FUEL TYPES

Identification Letter	Situations
A	1985 baseline prices, normal production costs, high yields, diesel power
B	1985 high demand prices, normal production costs, high yields, diesel power.

Identification Letter	Situation
C	1985 baseline prices, normal production costs, high yields, electric power.
D	1985 high demand prices, normal production costs, high yields, electric power.
E	1985 baseline prices, normal production costs, average yields, diesel power.
F	1985 high demand prices, normal production costs, average yields, diesel power.
G	1985 baseline prices, normal production costs, average yields, electric power.
H	1985 high demand prices, normal production costs, average yields, electric power.
I	1985 baseline prices, normal production costs, high yields, diesel power, non-irrigated versus irrigated rotation.
J	1985 high demand prices, normal production costs, high yields, diesel power, non-iirigated versus irrigated rotation.
K	1985 baseline prices, normal production costs, high yields, electric power, non-irrigated versus irrigated rotation.
L	1985 high demand prices, normal production costs, high yields, electric power, non-irrigated versus irrigated rotation.
M	1985 baseline prices, normal production costs, average yields, diesel power, non-irrigated versus irrigated rotation.
N	1985 high demand prices, normal production costs, average yields, diesel power, non-irrigated versus irrigated rotation.
O	1985 baseline prices, normal production costs, average yields, electric power, non-irrigated versus irrigated rotation.
P	1985 high demand prices, normal production costs, average yields, electric power, non-irrigated versus irrigated rotation.

Identification Letter	Situations
Q	1985 baseline prices, 33% increase in variable production costs, high yields, diesel power, non-irrigated versus irrigated rotation.
R	1985 high demand prices, 33% increase in variable production costs, high yields, diesel power, non-irrigated versus irrigated rotation.
S	1985 baseline prices, 33% increase in variable production costs, high yields, electric power, non-irrigated versus irrigated rotation.
T	1985 high demand prices, 33% increase in variable production costs, high yields, electric power, non-irrigated versus irrigated rotation.
U	1985 baseline prices, 33% increase in variable production costs, average yields, diesel power, non-irrigated versus irrigated rotation.
V	1985 high demand prices, 33% increase in variable production costs, average yields, diesel power, non-irrigated versus irrigated rotation.
W	1985 baseline prices, 33% increase in variable production costs, average yields, electric power, non-irrigated versus irrigated rotation.
X	1985 high demand prices, 33% increase in variable production costs, average yields, electric power, non-irrigated versus irrigated rotation.

For the purpose of determining the potential increase of irrigation in the Mississippi Delta Region the rotations which are considered best in each soil group are very important. In the analysis of the first eight situations listed (A-H), one best rotation exists in each soil group. "Best rotation" refers to that rotation with the lowest cost/benefit ratio. If no rotation with a cost/benefit ratio of less than one exists on a particular soil group irrigation is not economically feasible.

In situations I through X the potential for irrigating each rotation is compared to the dryland farming of the same rotation as opposed to the "best" dryland rotation.

Situation "A" assumes 1985 baseline crop prices, normal production costs, high level management, diesel fuel as the source of power for the irrigation systems, and opportunity costs based on the "best" rotation. The cost/benefit ratios for Situation "A" are shown in Appendix Table A-1. Irrigation is economically feasible on soil groups 1, 2, 3, 4, 7, and 8. Soil groups 5, 6, and 9 have no cost/benefit ratios less than one. On soil groups 1, 2, 4, 7, and 8 the irrigated cotton-soybean rotation is determined to be the most favorable. Soil group 3 shows the irrigated corn-soybean rotation providing the highest rate of return.

Situation "B" is identical to "A" except that crop prices are increased to 1985 high demand levels. Soil groups 1, 2, 7, and 8 remain favorable for irrigation with the cotton-soybean rotation, as in Situation "A", being the most feasible. Soil groups 3 and 4, which had previously been in the cotton-soybean rotation, and soil group 6, which had not been irrigated in Situation "A", all have cost/benefit ratios of less than one in the rice-soybean/wheat-soybean rotation. The change in rotations for soil groups 3 and 4 is explained by the relative changes in crop prices. Changing crop prices from 1985 baseline to 1985 high demand increases the rice price 34% and the cotton price only 14%. Soil groups 5 and 9 remain unprofitable for irrigation. The cost/benefit ratios for Situation "B" are shown in Appendix Table A-2.

In Situations "C" and "D" all assumptions are identical to Situations "A" and "B" respectively, except that electric power rather than diesel is used for irrigation. The cost/benefit ratios for Situations "C" and "D", shown in Appendix Tables A-3 and A-4, are lower than in Situations "A" and "B" because electricity is a cheaper power source than diesel. There are no changes in the rotations or the soil groups that would be irrigated except that soil group 9, which was not irrigated in Situation "B", has a cost/benefit ratio less than one with the soybean-soybean/wheat rotation in Situation "D". This soil group had been only marginally unprofitable under the previous situation and the lower cost of electric power enabled it drop below one. Irrigation of soil groups 5, 6, and 9 remain unfeasible assuming 1985 baseline crop prices and soil group 5 remains unfeasible assuming 1985 high demand crop prices.

The four situations just discussed were based on a high level of management. The differences that exist dealt with the changes in crop prices and fuel sources. Opportunity costs are calculated by multiplying the soil group crop yield for dryland production by the appropriate crop price. The dryland production costs are then subtracted from this figure to estimate those returns foregone by producing irrigated crops. For example, whichever set of crop prices are used, they are also used to compute opportunity costs. Therefore, the changes in total revenue resulting from raising or lowering of crop prices do not necessarily result in a high or lower cost/benefit ratio because the effects are offset to some degree by the changes in opportunity cost.

EFFECT OF CHANGING YIELD ESTIMATES

In situations E through H the potential for increasing irrigation by average managers is analyzed. The corn-soybean rotation is excluded from consideration because it is assumed that farmers raising irrigated corn are representative of high level management.

The cost/benefit ratios of average managers in almost all situations are lower than those for high level managers. That is, the potential for increasing returns through the use of irrigation is greater for average than for high level managers. This results from two causes: 1) average managers have lower opportunity costs than high level managers when comparing irrigated to non-irrigated crop production, and 2) the yield response to irrigation has been found to be higher on a percentage basis for average managers than it is for high level managers. Irrigation yield data was collected in the survey of farmers in the Delta region. This data was aggregated into two groups based on dryland yields. Those producers who have dryland yields at or below the average dryland yield for the entire sample are representative of average management. Those producers who have dryland yields above the average for the sample are representative of high level management. The irrigation yield responses were averaged for each group. It was found that average managers increase yields by a larger percentage than do high level managers. This difference might occur for any or all of three reasons: 1) average managers have lower dryland yields which result in lower bases on which percentages are calculated; 2) it may be that average managers who install irrigation systems begin to pay more attention to other production practices (practices that high level managers already use); 3) average managers may tend to farm less naturally productive land that responds well to water.

Situation "E" assumes 1985 baseline crop prices, normal production costs, average management, and diesel power for irrigation. The cost/benefit ratios for this situation are shown in Appendix Table A-5. The cotton-soybean rotation is the first choice in soil groups 1, 7, and 8. In soil groups 3, 4, 6, and 9 the soybean-soybean/wheat rotation is the best rotation. Irrigation of soil groups 2 and 5 is not profitable under situation "E" conditions. Both of these soil groups require center pivot irrigation unless land formed. Center pivot was found to be the most expensive of all systems examined. This relatively high cost could not be overcome with the yield increases found for these soils.

Situation "E" is identical to situation "A" except for yield levels. The changes in yields cause some changes in favored rotations between the two situations. When yields are lowered to average management levels only the best cotton soil groups; 1, 7, and 8; remain in cotton. In this case average cotton yields were simply not high enough to allow the cotton rotation to be first in soil groups 2 and 4. In soil group 2 no rotation has a cost/benefit ratio less than one and in soil group 4 the soybean-soybean/wheat rotation is most favorable. Soil groups 6 and 9, which were not feasible for irrigation in situation "A", both come into irrigation with the soybean-soybean/wheat rotation at the average yield level. Soil group 3, which had been in corn-soybeans in situation "A", remains in irrigated acreage but the rotation is changed to soybean-soybean/wheat since corn is not considered for average management.

Changing crop prices from 1985 baseline (situation "E") to 1985 high demand (situation "F") results in several changes. Since all other assumptions are the same, the changes can be traced to changes in crop prices. In situation "F" all soil groups except soil group 5 have cost/benefit ratios less than one. Soil group 1, which was in the cotton rotation under situation "E", and soil groups 3, 4, and 6, which were in the soybean-soybean/wheat rotation, change to rice rotations. This movement was discussed previously and explained by the relative changes in crop prices between the two price levels. Soil group 2, which was not economically attractive for irrigation in situation "E", is attractive with 1985 high demand prices in cotton rotation. Soil groups 7 and 8 remain in cotton-soybeans and soil group 9 remains in soybeans-soybeans/wheat. Soil group 5 still does not come into irrigation. The cost/benefit ratios for situation "F" are shown in Appendix Table A-6.

Situation "G" assumes 1985 baseline crop prices, normal production costs, average management, and electric power for irrigation. It is identical to situation "E" except for the power source. All soil groups except soil group 5 are favorable for irrigation. The cost/benefit ratios, shown in Appendix Table A-7, are lower than in situation "E" because of the lower relative cost of electricity as opposed to diesel fuel as an irrigation power source. There are only two differences in best rotation or soil groups with cost/benefit ratios under one between the two situations. Soil group 2 did not come into irrigation in Situation "E". In situation "G" it comes in with the cotton-soybean rotation. Soil group 3, the highest yielding rice soil group, went out of the soybean-soybean/wheat rotation and into the rice-soybean/wheat-soybean rotation. This can also be explained by the lower cost of electricity since pumping costs for rice production make up a larger proportion of irrigation costs than they do for other crops.

Situation "H" is identical to situation "G" except that crop prices are changed from 1985 baseline to 1985 high demand. The relatively large price increase for rice coupled with the relatively low irrigation cost of electricity bring several soil group into rice rotations. Soil group 1 changes from the cotton rotation to rice-soybean-soybean. Soil group 3 remains in the rice-soybean/wheat-soybean rotation and soil groups 4 and 6 move into this rotation from the soybean-soybean/wheat rotation. Every soil group physically capable of rice production moves into rice rotations under the conditions of situation "H". Soil groups 2, 7, and 8 all remain in the cotton rotation and soil group 9 remains in soybean-soybean/wheat. For the first time soil group 5 is economically feasible for irrigation with the soybean-soybean/wheat rotation. With the inclusion of soil group 5, all soil groups would be irrigated. The cost/benefit ratios for situation "H" are shown in Appendix Table A-8.

EFFECT OF CHANGING CALCULATION METHOD FOR OPPORTUNITY COSTS

The cost/benefit ratio analysis for situations I through X differs from situations A through H in that opportunity costs assumed for each rotation are equal to the returns above specified costs for that same rotation under dryland conditions. In this case "dryland conditions" for rice rotations would mean that the crops rotated with rice would be "dryland". The rice, of course, would still be irrigated.

This additional analysis was felt to be necessary because many farmers may not have any or all of their land planted to the rotation providing the highest rate of return. In many cases in situations A through H the cotton-soybean rotation appeared as the one best dryland rotation for many soil groups. However, it was found through personal interviews with farmers and agronomy experts, that in recent years many Delta producers have cut back their cotton acreage or no longer produce cotton. The reasoning behind the decrease in cotton production stems from recent low lint prices, high capital requirements, and increased restrictions on pesticide use. Cotton producers who have decreased their acreage or gotten out of cotton completely are likely to find it quite expensive to increase acreage or get back into cotton production if they have sold the necessary equipment to produce this crop.

In situations I through P each rotation is compared on a non-irrigated basis against this same rotation on an irrigated basis. The cost/benefit ratio is used to determine if adding irrigation to this non-irrigated rotation will improve economic returns. If the cost/benefit ratio derived is less than one it will be considered economically feasible to irrigate. In addition, in situations Q through X the variable production costs will be increased by 33 percent to determine what effect this will have on future irrigation feasibility.

Situation "I" assumes 1985 baseline crop prices, normal production costs, high level management, and diesel power for irrigation. All soil groups except soil group 5 are favorable for irrigation. The greatest change from the different method of calculating opportunity cost is that the corn-soybean rotation provides the highest rate of return on soil groups 1, 3, and 9. The entry of the corn rotation on such a large scale is attributed to the tremendous increases in corn yields, and therefore total revenue, as a result of irrigation water applied at critical times of crop development. Since the rotation is now, in effect, being compared with itself instead of the "highest use" dryland rotation, the cost/benefit ratios are significantly lower than previously. In soil groups 2, 7, and 8 the cotton rotation remains the most favorable. Soil groups 7 and 8 are the highest yielding soil groups for cotton and in soil group 2 most alternative rotations are simply poor compared with other soil groups. In soil groups 4 and 6, on which corn is not an alternative due to the clay soils, the soybean-soybean/wheat and rice-soybean-soybean rotations, respectivley, are the best rotations. The cost/benefit ratios for situation "I" are presented in Appendix Table A-9.

Situation "J" is identical to situation "I" except that crop prices are increased to 1985 high demand levels. The cost/benefit ratios are shown in Appendix Table A-10. On soil gruops 1, 2, 3, and 9 the corn-soybean rotation is the most feasible. Only soil group 2 was not in this rotation in situation "I". It appears that the slightly larger price increase for corn allowed this rotation to slightly surpass the cotton rotation for this soil group. Soil groups 4, 6, 7, and 8 do not change rotations. Soil group 5 remains unfavorable for irrigation.

Situations "K" and "L" examined electricity as the source of irrigation power under the same conditions as diesel power was examined in situations

"I" and "J", respectively. In both situations the results are nearly identical. The corn-soybean rotation is preferred on soil groups 1, 3, and 9 in both situations. The cotton-soybean rotation is favored on soil groups 4, 7, and 8 in both situations. Soil group 6 is in the rice-soybean-soybean rotation in both situations. Only on soil group 2 is there a difference. In situation "K" this soil group is in the cotton-soybean rotation and in situation "L" it is in the corn-soybean rotation. There are very small differences in the cost/benefit ratios for these rotations in both situations. Soil group 5 is not irrigated in either of the situations. The cost/benefit ratios for situations "K" and "L" are shown in Appendix Tables A-11 and A-12, respectively.

EFFECT OF CHANGING YIELD ESTIMATES

Situations M through P deal with average level management compared to situations I through L that dealt with high level management. With the exception of yields, the same assumptions apply to situations M through P as were discussed earlier in the chapter dealing with situations E through H. As mentioned previously, the economic feasibility of irrigation for the average manager appears higher than that of the high level manager because of lower opportunity costs and greater percentage yield increases due to irrigation.

Situation "M" assumes 1985 baseline crop prices, normal production costs, average management and diesel powered irrigation. On soil groups 1, 7, and 8 the cotton-soybean rotation is most feasible. Soil groups 3, 4, 6, and 9 have cost/benefit ratios under one with the soybean-soybean/wheat rotation. Neither soil group 2 nor 5 have rotations that are favorable. Cost/benefit ratios for situation "M" are presented in Appendix Table A-13.

When crop prices are increased to 1985 high demand levels, as in situation "N", only small changes occur in the preferred rotations. Soil groups 1, 7, and 8; in the cotton-soybean rotation under 1985 baseline crop prices; remain in this rotation and soil group 2, which was not irrigated under 1985 baseline crop prices, moves into the cotton rotation. Soil groups 3, 4, 6, and 9 remain in the soybean-soybean/wheat rotation. It should also be noted that all rotations are feasible on soil groups 1, 4, 6, 7, 8, and 9 regardless of the type of irrgation system used. Irrigation of soil group 5 remains unprofitable. As discussed earlier in the chapter, soil group 5 must be irrigated with center pivot irrigation due to the gently undulating slope. Center pivot systems are the most expensive of all systems examined. In addition, soil group 5 has a relatively low yield response to irrigation compared with other soil groups. Cost/benefit ratios for situation "N" are shown in Appendix Table A-14.

Situations "O" and "P" examine average management and electric power for irrigation under 1985 baseline and high demand crop prices, respectively. There are only two changes, one due to lower cost electricity (as compared to diesel) and one due to changes in crop prices. In situation "O" the change to electric power brings soil group 2 into irrigation with the cotton-soybean rotation. In situation "P" the increase in crop prices to high demand levels combined with electric power to bring soil group 5 into irrigation with the soybean-soybean/wheat rotation. Other than those two changes the results of situations "M", "N", "O", and "P" are identical. Soil groups 1, 7, and 8 remain in cotton-soybeans and soil groups 3, 4, 6, and 9 remain in the soybean-soybean/wheat rotation in both situations "O" and "P". The cost/benefit ratios for these situations are shown in Appendix Tables A-15 and A-16, respectively.

EFFECTS OF INCREASING VARIABLE PRODUCTION COSTS BY 33 PERCENT

In situations Q through X variable production costs are increased by 33 percent with all other assumptions identical to situations I through P, respectively. The cost/benefit ratios for situations Q through T, all of which assume high level management, increase by from one to three percent above those same situations computed with normal production costs (i.e., I - L). Only the marginally favorable cost/benefit ratios in situations I through L became unfavorable with the 33 percent increase in variable production costs. These marginal cost/benefit ratios were generally in the .98 to .99 category with normal production costs.

In situations U though X, which assume average management, significant increases in the cost/benefit ratios occur for some rotations and soil groups. This is explained by the narrower profit margins for average managers as opposed to high level managers. Average managers are much more sensitive to increased costs than are high level managers. Even though average managers increase yields by a greater percentage with irrigation than do high level managers, average management yields are still lower than high level management yields. Since both groups are assumed to have essentially the same production costs, profit margins are smaller for average managers. In some situations the 33 percent increase in variable costs converts a favorable irrigation decision to an unfavorable decision. The cost/benefit ratios for situations "Q", "R", "S", "T", "U", "V", "W", and "X" are presented in Appendix Tables A-17, A-18, A-19, A-20, A-21, A-22, A-23, and A-24, respectively.

CHAPTER 4

POTENTIAL INCREASE IN SOYBEAN PRODUCTION

Soybeans are the dominant crop of the Mississippi Delta Region. Soybeans are grown on 70-75 percent of the total cropland acreage of the delta every year, and are included in almost every crop rotation.

Crop rotations play an important role in determining the number of acres planted to soybeans. Soybean production within a crop rotation system ranges from 50 percent of the acreage in the cotton-soybean rotation to 100 percent of the acreage in the soybean-soybean/wheat rotation.

DETERMINATION OF REGIONAL ACREAGE AND SOYBEAN YIELDS

Regional acreage and soybean yields are taken from research by Shulstad, May and Herrington in a cropland conversion study for the Mississippi Delta Region. Their study considered 25,360,000 acres to be within the Mississipi Delta. The Grand Prairie of Arkansas is excluded in this study because the soils of this area are not representative of the remaining Delta Region. For the purposes of this study the Mississippi Delta Region encompasses 24,160,000 acres, including 17,641,546 acres of cropland in nine soil groups. Cropland accounts for 73 percent of the total acreage in the Delta Region. The remainder is made up of urban areas, timber, pasture, orchards, and water.

An average soybean yield of 21.7 bushels per acre was reported for the six county sample area during 1975-1978. This average is multiplied by the acres in soybean production to determine the number of bushels of soybeans produced under the existing situation. The base will be used to compute the percentage increases in soybean production possible through increased use of irrigation.

THE POTENTIAL FOR INCREASING SOYBEAN PRODUCTION IN THE DELTA REGION

The potential for increasing soybean production in the Mississippi Delta Region through irrigation is presented in Tables 4-1 and 4-2. Table 4-1 presents those situations in which diesel powered irrigation systems are used. Situations utilizing electric power are shown in Table 4-2. The assumptions for each situation were presented in Table 3-1.

Table 4-1 assumes 100 percent use of diesel power for irrigation. The economic feasibility of diesel powered irrigation is highly sensitive to variation in yields, product prices and variable cost. All of these factors make a difference in the cost/benefit ratios for each situation. These factors lead to the selection of the most feasible crop rotation which will in turn determine the number of acres of soybeans to be irrigated. In the cotton-soybean rotation soybeans will be grown every other year. In the rice-soybean-soybean rotation soybeans will be grown two out of three years. Soybeans will be produced every year in the soybean-soybean/wheat rotation.

TABLE 4-1

POTENTIAL INCREASE IN SOYBEAN PRODUCTION ASSUMING 100 PERCENT DIESEL POWERED IRRIGATION

Situation	Total Land Irrigated (Acres)	Soybeans Irrigated (Acres)	Increase in Soybean Production (Bushels)	Increase in Soybean Production (Percent)
A	16,273,521	10,710,188	198,020,989	71.0%
B	16,441,772	9,334,713	122,858,482	44.0%
E	15,958,308	10,972,703	105,256,959	37.7%
F	17,041,659	10,670,138	76,840,941	27.5%
I	16,861,659	11,173,099	196,400,613	70.4%
J	16,861,659	11,727,739	196,387,660	70.3%
M	15,958,308	10,972,703	105,256,965	37.7%
N	17,041,659	11,514,378	109,590,356	39.3%
Q	16,426,568	10,710,188	193,001,735	69.2%
R	16,737,299	11,020,919	195,487,583	70.0%
U	9,893,220	7,940,159	74,931,516	26.8%
V	15,958,308	10,972,703	105,256,965	37.7%

TABLE 4-2

POTENTIAL INCREASE IN SOYBEAN PRODUCTION ASSUMING 100 PERCENT ELECTRIC POWERED IRRIGATION

Situation	Total Land Irrigated (Acres)	Soybeans Irrigated (Acres)	Increase In Soybean Production (Bushels)	Increase In Soybean Production (Percent)
C	16,273,521	10,710,188	198,020,989	71.0%
D	17,041,659	9,639,073	125,293,362	44.9%
G	17,041,659	11,490,583	98,007,155	35.1%
H	17,641,546	11,270,025	82,839,811	29.7%
K	16,861,659	8,599,670	93,450,498	33.4%
L	17,041,659	8,599,670	76,653,662	27.5%
O	17,041,659	11,514,378	98,792,390	35.4%
P	17,641,659	12,655,940	129,131,101	46.3%
S	16,426,568	8,136,759	90,064,573	32.3%
T	17,041,659	8,599,670	93,463,501	33.5%
W	9,893,220	7,940,159	74,931,516	26.8%
X	15,958,308	10,972,703	94,459,010	33.8%

Situation "A", which assumes 1985 baseline prices, normal production cost, high yields and diesel power, results in the greatest potential for expanding soybean production through the use of irrigation. In situation "A" 16,273,521 acres are irrigated including 10,710,188 acres of soybeans producing 198,020,989 bushes. This represents an increase of 71.0 percent in soybean production over 1978 production levels.

Situation "U", which assumes baseline prices, a 33 percent increase in costs, average yields, and diesel power, provides the least potential for expanding soybean production. The number of acres irrigated is 9,893,220. Acres of soybeans irrigated is 7,940,159 producing 74,931,516 bushes or a 26.8 percent increase due to irrigation.

The primary reason for the difference in situations "A" and "U" is the increase of 33 percent in variable production cost. The increase resulted in a cost/benefit ratio greater than one for all alternative irrigation systems and crop rotations in some soil groups. Thus the 3,000,000 acres in soil group 1, for example, can more profitably be farmed on a dryland basis, even though total production will decline.

Table 4-2 assumes 100 percent electric power for irrigation. The same range exists for Table 4-2 as that of Table 4-1. Situation "C" will result in a 71.0 percent increase in soybean production while situation "W" will result in a 26.8 percent increase in soybean production.

Differences do exist between diesel and electric power in the determination of acres of cropland irrigated. It was shown earlier that electricity is the most economical source of power for the operation of irrigation equipment. The differences in cost go into the determination of the cost/benefit ratio and the derivation of the most feasible crop rotation.

The selection of the crop rotation plays an important role in determining the number of acres of irrigated soybeans. This is shown in situations S-Q and T-R respectively. These situations are the same except for a difference in fuel source. In situations "S" and "T", electric power is used and soil group four will be planted with the cotton-soybean rotation. In situations "Q" and "R" diesel power is used and the soybean-soybean/wheat rotation is chosen for soil group four. The difference in crop rotation accounts for a decrease of 100,000,000 bushels of soybeans in situations "S" and "T" compared to that of "Q" and "R".

Pairing the best cost/benefit ratios for each soil productivity group and land use and ranking them in ascending order produces new total irrigated acreage and irrigated soybean acreage supply functions. Expanding the information from the six county sample produces estimates for the entire Mississippi Delta Region. The potential total irrigated acreage and irrigated soybean acreage supply functions under all situations discussed in the study are shown in the Appendix.

PRESENT AND FUTURE PROJECTIONS OF PERCENTAGE OF DIESEL AND ELECTRIC POWER FOR IRRIGATION SYSTEMS

Tables 4-3 and 4-4 assume a division between diesel and electric power units. Table 4-3 assumes that 50 percent of the irrigation systems are powered electrically and the other 50 percent are powered by diesel. Diesel is used as a proxy for all internal combustion power sources even though natural gas and L.P. gas units do exist in the study area. The 50-50 split is representative of the present situation in the delta.

TABLE 4-3

IRRIGATED SOYBEAN PRODUCTION UTILIZING 50 PERCENT ELECTRIC AND 50 PERCENT DIESEL POWER FOR IRRIGATION

Situation	Total Land Irrigated (Acres)	Soybeans Irrigated (Acres	Increase in Soybean Production (Bushels)	Increase in Soybean Production (Percent)
A-C	16,273,521	10,710,188	198,020,989	71.0%
B-D	16,741,715	9,486,893	125,075,922	44.4%
E-G	16,499,984	11,231,642	101,632,056	36.4%
F-H	17,341,602	10,970,081	79,840,376	28.6%
I-K	16,861,659	9,886,384	144,925,555	51.9%
J-L	16,951,659	10,163,705	136,520,661	48.8%
M-O	16,499,984	11,243,541	102,024,678	36.6%
N-P	17,341,603	12,085,159	118,360,729	42.8%
Q-S	16,426,568	9,423,474	141,533,154	50.8%
R-T	16,889,479	9,810,295	144,475,542	51.8%
U-W	9,893,220	7,940,159	74,931,516	26.8%
V-X	15,958,308	10,972,703	102,857,988	35.8%

TABLE 4-4

IRRIGATED SOYBEAN PRODUCTION UTILIZING 60 PERCENT ELECTRIC AND 40 PERCENT DIESEL POWER FOR IRRIGATION

Situation	Total Land Irrigated (Acres)	Soybeans Irrigated (Acres)	Increase in Soybean Production (Bushels)	Increase in Soybean Production (Percent)
A-C	16,273,521	10,710,188	198,020,989	71.0%
B-D	16,681,726	9,456,457	123,832,434	44.3%
E-G	16,608,319	11,283,431	100,907,075	36.1%
F-H	17,281,613	10,910,092	111,376,413	28.3%
I-K	16,861,659	10,143,727	155,220,567	55.6%
J-L	16,969,659	9,850,898	124,547,261.2	44.6%
M-O	16,608,318.	11,297,708	101,378,220	36.3%
N-P	17,401,592	12,199,315	121,314,803	43.5%
Q-S	16,426,568	9,166,130	131,239,438	47.1%
R-T	16,919,915	9,568,170	134,273,134	48.1%
U-W	9,893,220	7,940,159	74,931,516	26.8%
V-X	15,958,308	10,972,703	102,857,988	35.8%

A future projection is made in Table 4-4. Electric power is less expensive to operate than diesel power on irrigation equipment. It is assumed that farmers will shift to electric power units as their existing units needed replacement, provided electric power is available. In Table 4-4 electric power accounts for sixty percent of the power compared to forty percent for diesel. This assumption is based on the fact that 1) operating costs of electric power are lower and 2) the price of electricity is not as directly related to the price of oil as diesel fuel.

One important consideration that will slow the spread of electric power units is the location of wells in relation to a three-phase power line. Only farmers having ready access to this power souce can convert economically.

Results in Tables 4-3 and 4-4 are similar to Tables 4-1 and 4-2. The same range of a low of 26.8 percent and a high of 71.0 percent increase in soybean production is shown. Differences in Table 4-3 and 4-4 are only slight and can be explained by electricity now being the dominant fuel source. Use of the lower cost electric power will cause different crop rotations, generally those with higher water using crops to be selected as the most economically feasible.

POTENTIAL SOYBEAN ACREAGE IRRIGATED BY FURROW AND CENTER-PIVOT IRRIGATION

Present in Table 4-5 are the potential number of irrigated acres of soybeans within the Mississippi Delta region broken down by furrow and center-pivot irrigation.[5] The percent of possible irrigated acreage

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[5] Flood irrigation was considered in the analysis but was always found to be a less efficient technique than furrow irrigation.

TABLE 4-5

SOYBEAN ACREAGE IRRIGATED
BY FURROW AND CENTER-PIVOT IRRIGATION

	Furrow Irrigation		Center Pivot		
Situation	Irrigated Soybean Acreage	Percent of Total Irrigated Soybean Acreage	Irrigated Soybean Acreage	Percent of Total Irrigated Soybean Acreage	Total Irrigated Soybean Acreage
A	9,935,998	93%	774,190	7%	10,710,188
B	8,560,523	92%	774,190	8%	9,334,713
C	9,935,998	93%	774,190	7%	10,710,188
D	8,864,883	92%	774,190	8%	9,639,073
E	10,740,188	98%	232,515	2%	10,972,703
F	9,895,948	93%	774,190	7%	10,670,138
G	10,716,393	93%	774,190	7%	11,490,583
H	9,895,948	88%	1,374,077	12%	11,270,025
I	10,398,909	93%	774,190	7%	11,173,099
J	10,953,549	93%	774,190	7%	11,727,739
K	7,825,480	91%	774,190	9%	8,599,670
L	7,825,480	91%	774,190	9%	8,599,670
M	10,740,188	98%	232,515	2%	10,972,703
N	10,740,188	93%	774,190	7%	11,514,378
O	10,770,188	93%	774,190	7%	11,514,378
P	10,740,187	85%	1,915,753	15%	12,655,940
Q	9,935,998	93%	774,190	7%	10,710,188
R	10,246,729	93%	774,190	7%	11,020,919
S	7,362,569	90%	774,190	10%	8,135,759
T	7,825,480	91%	774,190	9%	8,599,670
U	7,707,644	97%	232,515	3%	7,940,159
V	10,740,188	98%	232,515	2%	10,972,703
W	7,707,644	97%	232,515	3%	7,940,159
X	10,740,188	98%	232,515	2%	10,972,703

along with total acreage irrigated also broken down by systems is shown in Table 4-6.

Furrow irrigation is considered physically possible on 15,493,278 acres of cropland in the study area made up of soil groups 1, 3, 4, 6, 7, and 9. Soil groups 2, 5, and 8 contain 2, 148,368 acres of cropland which because of their slope can only be irrigated with a center-pivot system. Some soils in these groups could be irrigated with a furrow system if the land were formed through precision land leveling.[6] The acreage irrigable by furrow and the acreage only irrigable by center pivot combine to give a total cropland acreage for the study area of 17,641,546 acres that are physically possible to irrigate.

The acreage of furrow irrigation which is economically feasible ranges from a high of 15,493,278 acres in situations D, E, F, G, H, I, J, K, L, M, N, O, P, T, V, and X or 100 percent of possible acreage to a low of 9,428,190 acres in situations "U" and "W" or 60 percent of possible acreage. In situations "U" and "W" the acreage in soil group 1 is not economically feasible to irrigate.

Center-pivot irrigation must be utilized on soil groups 2, 5, and 8. Economically feasible irrigated acres range from a high of 2,148,268 acres in situations H, N, or 100 percent of the possible irrigated acreage to a low of 465,030 irrigated acres in situations E, L, T, U, and V, or 21.6 percent of the possible irrigated acreage.

Under situation H, the most advantageous situation occurred. Furrow and center-pivot irrigation combine to irrigate 17,641,546 acres, 100 percent of total delta cropland, or 73.0 percent of total delta land area.

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[6] Investigation of the economic feasibility of furrow irrigation following land leveling is the subject of a thesis by Blake Phillips.

Situations "U" and "W" are considered the least feasible situations. Furrow and center-pivot irrigation combine to irrigate 9,893,220 acres, 56.1 percent of total delta cropland, or 40.9 percent of total land in the Mississippi Delta region.

TABLE 4-6

ACREAGE IRRIGATED BY FURROW AND CENTER PIVOT IRRIGATION

Situation	Furrow Irrigated Acreage	Percent of Possible Furrow Irrigated Acreage	Center-Pivot Irrigated Acreage	Percent of Possible Center-Pivot Irrigated Acreage	Total Irrigated Cropland Acres	Percent of Delta Cropland	Percent of Total Delta Land
A	14,725,140	95.0%	1,548,381	72.0%	16,273,521	92.2%	67.4%
B	15,188,918	98.0%	1,548,381	72.0%	16,737,299	94.9%	69.3%
C	14,725,140	95.0%	1,548,381	72.0%	16,273,521	92.2%	67.4%
D	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
E	15,493,278	100.0%	465,030	21.0%	15,958,308	90.5%	66.1%
F	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
G	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.0%
H	15,493,278	100.0%	2,148,268	100.0%	17,641,546	100.0%	73.0%
I	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
J	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
K	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
L	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
M	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
N	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
O	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
P	15,493,278	100.0%	1,548,381	72.0%	17,041,659	96.6%	70.5%
Q	14,725,140	95.0%	1,548,381	72.0%	16,273,521	92.2%	67.4%
R	15,188,918	98.0%	1,548,381	72.0%	16,737,299	94.9%	69.3%
S	14,725,140	95.0%	1,548,381	72.0%	16,273,521	92.2%	67.4%
T	15,493,278	100.0%	465,030	21.6%	15,958,308	90.5%	66.1%
U	9,428,190	60.8%	465,030	21.6%	9,893,220	56.1%	40.9%
V	15,493,278	100.0%	465,030	21.6%	15,958,308	90.5%	66.1%
W	9,428,190	60.8%	465,030	21.6%	9,893,220	56.1%	40.9%
X	15,493,278	100.0%	465,030	21.6%	15,958,308	90.5%	66.1%

CHAPTER 5

SUMMARY AND IMPLICATIONS

The major objective of this study was to determine the potential for irrigation expansion in the Mississippi Delta Region. That is, how many acres of a particular soil group can be economically irrigated assuming alternative types of irrigation systems, production costs, product prices, and levels of management.

The economic analysis incorporated all irrigation cost and yield factors determined for a six county representative area in eastern Arkansas. Two levels of crop prices, two levels of crop yields, two levels of production costs, two types of opportunity costs calculations, and six different crop rotations were used to simulate twenty-four situations.

A total of 17,641,546 acres within the Mississippi Delta Region possess the physical characteristics that permit irrigation. A total of 15,493,278 acres can be irrigated through the use of any of the three techniques examined, furrow, flood, or center pivot irrigation. An additional 2,148,268 acres have potential for center pivot irrigation only due to excessive or uneven slope.

Furrow irrigation is the most economical alternative for all soils where the technique is physically possible. Under the assumptions examined for 16 of the 24 situations it is economically feasible to irrigate all of the potential 15,493,278 acres of cropland with furrow irrigation. The feasibility for increasing irrigation within the Delta region is decreased only under the most unfavorable situation examined; 1985 baseline crop prices, 33 percent increase in variable production costs, and average yields. If these conditions prevail it is economical to irrigate only 60 percent of the potential furrow irrigated acres, or 9,428,190 acres.

There are 2,148,268 acres of Delta cropland that are either too steep or undulating to permit furrow irrigation. Center pivot irrigation is the only choice for this acreage unless land forming is used to create the proper slope. The potential for center pivot irrigation ranges from 2,148,268 acres, or 100 percent of the potential center pivot irrigated acreage, to 465,030 acres across the various situations examined. In 17 of the 24 situations examined center pivot irrigation was feasible on 1,548,381 acres. This figure would account for 72 percent of the potential center pivot irrigated acreage.

The estimated potential regional increase in soybean production resulting from irrigation ranges from an increase of 198,020,989 bushels, a 71 percent increase, to 74,931,516 bushes, a 26.8 percent increase. In 20 of the 24 situations examined the increase in regional soybean production ranges between 35 and 55 percent. Much of the difference in these figures results from whether average or high level management is assumed. In 22 of the 24 situations examined, at least 90.5% of the region's cropland could be profitably irrigated. For the six county sample area this percentage would constitute approximatley 1,866,318 acres. However, the Federal Census indicates only 180,762 acres, or 9.7% of sample area cropland, was irrigated in 1978. If a nearly ten fold increase in irrigated acreage can be justified, why has it not yet occurred?

The answer is that this increase is occurring but is limited in the short run by several factors. The first factor is the availability of capital. This project has assumed that adequate capital is available for irrigation expansion. However, to install irrigation systems on all profitable soil groups in the Delta region would require from 1.86 to 2.16 billion dollars at present costs, depending on fuel type used. Also, farmers would need capital to operate the systems plus their normal crop production capital requirements It is likely that this amount of capital would neither be desired nor available except over an extended period of time.

Another factor may be a lack of knowledge among farmers concerning irrigation investment costs, operating costs, and yield response. Until very recently little research tying these factors together has been done for the Delta region. Because of this lack of research producers have not had a firm foundation upon which to assess the profitability of irrigation.

Insufficient labor may also inhibit irrigation growth. Many farmers may have labor busy with other activities or may have difficulty in securing extra labor on a short term basis. It is interesting to note that this problem was mentioned most often by producers who had recently installed center pivot systems. Although these systems are a relatively expensive irrigation method, they require a minimum of labor compared with furrow or flood irrigation.

There is another time constraint that must be considered. Farmers may be reluctant to install irrigation during the cropping season since burial of underground pipe or assembly of some systems would result in trampling of standing crops. Because of this, irrigation installation could be limited to months outside the normal growing season. Many farmers would not view fallowing a field to install irrigation as a viable option.

In spite of these factors, irrigated acreage reported for the sample area in the Federal Census increased by 73,069 acres, or 67.8%, from 1974 to 1978. In addition, irrigation vendors in the area report increases in volume of business ranging from 50 to 100% per year from 1978 to 1980. With the disasterous drought of 1980 fresh in the minds of producers, all vendors expect volume to increase at an even faster rate in the near future. It is clear that a major shift into irrigated agriculture in the Delta region is developing. However, because of the factors discussed, this shift will not occur overnight.

IMPLICATIONS AND LIMITATIONS

Increases in soybean production as great as 71 percent can be obtained economically within the Mississippi Delta Region through the use of irrigation. Furrow irrigation was shown to be the dominant irrigation system that could be economically used in the study area. Furrow irrigation has the advantages of requiring less capital investment, using less power, and covering more acreage in a given field then center pivot irrigation. However, the labor requirements are extensive in the correct operation of furrow irrigation.

Center pivot irrigation requires a substantial capital investment, power requirements are high, and field corners are not irrigated with this method. Center pivot irrigation has the following advantages: 1) it can be used on land that cannot be furrow irrigated because of slope. 2) timeliness of irrigation is more easily controlled, 3) less water is applied than with furrow irrigation, 4) center pivot irrigation can be used as an insurance system to assure correct moisture levels for double cropping soybeans and wheat, reducing or eliminating the loss in soybean yields that commonly occur with a dryland double crop rotation, 5) labor requirements for the system are nominal.

The study did not consider the following aspects of the irrigation expansion issue: 1) the availability of labor necessary for furrow irrigation systems, 2) the tax advantages which serve to decrease the real cost of irrigation systems, particularly capital intensive center pivot systems, 3) the possibility of land forming those soils which cannot be furrow irrigated now and installing surface irrigation rather than center pivot irrigation, 4) the quality and quantity of water available for expanding irrigation.

ENVIRONMENTAL IMPLICATIONS

The environmental effects of irrigation in the Delta region can be qualitatively identified but not quantified. Researchers have not conducted adequate field work to quantify these potential effects. However, intensification of agricultural production in the area may result in some detrimental environmental effects.

The most visible environmental effects due to irrigation are damages from soil erosion and run off water containing pesticides and fertilizers. Excessive sediments loads due to erosion could increase water treatment costs for municipalities, damage domestic and industrial water supplies and water recreation, damage wildlife and fish populations, and lower aesthetic values. Mechanical removal of sediment from streams and lakes would be costly.

Erosion would also carry pesticides and fertilizers with the sediment. Irrigation of some crops might require greater amounts of these materials than would be used in dryland agriculture. Pesticides and fertilizers carried from the fields would enter the aquatic environment and might disrupt fish and other organisms crucial in the food chain. The greatest effects of these materials would be nitrate pollution of ground water, decreased supplies of dissolved oxygen in water and resultant growth of aquatic plants, and increased concentrations of salt in the water.

Proper management of irrigation should reduce these problems. In furrow or flood irrigation some sediment will be moved from the upper end of the field and deposited in the lower end. Over a period of years the field topography may change and sediment loads may be carried into adjacent water systems. However, a land plane can be used yearly to move this sediment back to its place of origin in the field thus returning the field to its original topography.

Furrow irrigation holds the greatest potential for severe erosion if used on slopes of greater than one percent, especially if the furrow stream has excess velocity at the end of the furrows. Good irrigation management can eliminate much of this problem. Center pivot irrigation would present fewer erosion problems than other systems because it is much like a rainfall event. Under the sprinkler system, the energy and droplet size can be controlled and the water applied at a rate that will minimize runoff.

Conversely, irrigation may have positive effects toward controlling erosion and runoff. Since yields and plant foliage are increased under irrigation, more crop residue will be available to turn back into the soil. The resulting build up of organic matter will reduce the intensity of runoff water and increase the infiltration rate, reducing the amount of runoff.

It is possible for irrigation practices to remove soil from a field but at the same time the possibility for decreasing soil movement also exists. If supplemental irrigation is to play a major role in meeting the increased demand for farm products in the region, farm managers must learn those irrigation techniques that minimize the chance of damages to the environment. Additional research concerning erosion resulting from irrigation needs to be performed so that producers in the area will know which techniques are most satisfactory.

Implications

Increases in soybean production as great as 71 percent can be economically attainable within the Mississippi Delta Region through the use of supplemental irrigation, although in 20 of the 24 situations examined the increases range between 35 and 55 percent. In 22 of the 24 situations examined, at least 90.5 percent of the region's cropland can be profitably irrigated. The environmental effects of this irrigation expansion are highly dependent upon techniques used by farm managers, with the possibility of being detrimental or beneficial for erosion and runoff control.

Robert N. Shulstad
Dr. Robert N. Shulstad
Co-Principal Investigator

Ralph D. May
Dr. Ralph D. May rns.
Co-Principal Investigator

SELECTED REFERENCES

Arkansas Cooperative Extension Service, *Arkansas Cotton Budgets, 1980 -- Production Cost Estimates*, Special Report 79, Little Rock, Arkansas, March, 1980.

Arkansas Cooperative Extension Service, *Arkansas Feed Grain Budgets, 1980 -- Production Cost Estimates*, Special Report 83, Little Rock, Arkansas, April, 1980.

Arkansas Cooperative Extension Services, *Arkansas Rice Budgets, 1980 -- Production Cost Estimates*, Special Report 81, Little Rock, Arkansas, March, 1980.

Arkansas Cooperative Extension Service, *Arkansas Soybean Budgets, 1980 -- Production Cost Estimates*, Special Report 80, Little Rock, Arkansas, March, 1980.

Capstick, Daniel F., *Economic Analysis of Irrigation and Fertilization of Cotton on Sharkey Clay and Grenada Silt Loam Soils in Eastern Arkansas*; Special Report 12, Agricultural Experiment Station, Division of Agriculture, University of Arkansas, Fayetteville, January, 1963.

Crosson, Pierre, Unpublished Memorandum: Price Projections, Resources for the Future, Inc., Washington, D.C., May, 1975.

Curtis, Larry M., John L. Boutwell, *Irrigation System Cost Analysis -'78*; Alabama Cooperative Extension Service, EE78-5, Auburn University, Auburn, Alabama, 1978.

Data Resources, Inc., *DRI Agricultural Service Quarterly Review*, Volume 3, Number 4, Data Resources, Inc., Lexington, Massachusetts, Winter, 1978.

Harris, Warren S., *Irrigation*, Agricultural Engineering Department, University of Arkansas, Fayetteville, 1977.

Herrington, Billey E., Jr., *The Economic Feasibility of Increasing Crop Production in the Mississippi Delta Region Through the Conversion of Non-Cropland to Cropland, and the Upgrading of Existing Cropland*, Unpublished M. S. Thesis, University of Arkansas Agricultural Economics Department, 1979.

Lacewell, Ronald D., Gary D. Condra, *The Effect of Changing Input and Product Prices on the Demand for Irrigation Water in Texas*, Technical Report 75, Texas Water Resources Institute, Texas A & M University, College Station, Texas, June 1976.

McVey, John L., Robert L. Williams, *Compairson of Irrigation Methods and Costs*, Mississippi Cooperative Extension Service, Mississippi State, Mississippi, 1979.

Mullins, Troy, Warren R. Grant, Wade F. Gregory, and William R. Morrison, World Rice Production Disappearance, and Trade 1960 Decade with Projections to 1980, Arkansas Agricultural Experiment Station, Bulletin 819 in cooperation with ERS, USDA, Fayetteville, Arkansas, March, 1977.

Thornson, Norman, and Lloyd K. Fischer, A Study of Irrigation Development in the Sandhills of Nebraska, Report 73, Agricultural Experiment Station, University of Nebraska - Lincoln, December, 1976.

White, James H., Gravity Irrigation on Cotton and Soybeans in Central Arkansas: An Economic Evaluation, Report Series 98, Agricultural Experiment Station, Division of Agriculture, University of Arkansas, Fayetteville, March, 1961.

White, James H., Sprinkler Irrigation in Eastern Arkansas: An Economic Evaluation, Report Series 62, Agricultural Experiment Station, Division of Agriculture, University of Arkansas, Fayetteville, December, 1956.

APPENDIX TABLE A-1

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "A"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.1004	1.0521	NA
	Rice - Soybeans/Wheat - Soybeans	1.0664	1.0238	NA
	Soybeans - Soybeans/Wheat	1.2118	1.1072	NA
	Cotton - Soybeans	NA	.8441	NA
	Grain Sorghum - Soybeans	1.6010	1.4989	NA
	Corn - Soybeans	NA	.9446	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.2823
	Cotton - Soybeans	NA	NA	.9634
	Grain Soybean - Soybeans	NA	NA	1.7027
	Corn - Soybeans	NA	NA	1.1977
3	Rice - Soybeans - Soybeans	1.0009	1.0675	NA
	Rice - Soybeans/Wheat - Soybeans	1.0422	1.0125	NA
	Soybeans - Soybeans/Wheat	1.1394	1.0722	NA
	Grain Sorghum - Soybeans	1.5143	1.4472	NA
	Corn - Soybeans	NA	.9305	NA
4	Rice - Soybeans - Soybeans	NA	1.0267	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9827	NA
	Soybeans - Soybeans/Wheat	NA	.9360	NA
	Cotton - Soybeans	NA	.9598	NA
	Grain Sorghum - Soybeans	NA	1.3802	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1349
	Cotton - Soybeans	NA	NA	1.0948
	Grain Sorghum - Soybeans	NA	NA	1.6069
6	Rice - Soybeans - Soybeans	NA	1.0966	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0296	NA
	Soybeans - Soybeans/Wheat	NA	1.0068	NA
	Grain Sorghum - Soybeans	NA	1.4794	NA
7	Soybeans - Soybeans/Wheat	1.01[illegible]	.9328	NA
	Cotton - Soybeans	NA	.7546	NA
	Grain Sorgum - Soybeans	1.3805	1.2950	NA
	Corn - Soybeans	NA	.9989	NA

APPENDIX TABLE A-1 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0644
	Cotton - Soybeans	NA	NA	.8457
	Grain Sorghum - Soybeans	NA	NA	1.4488
	Corn - Soybeans	NA	NA	1.1831
9	Soybeans - Soybeans/Wheat	1.0828	1.0169	NA
	Grain Sorghum - Soybeans	1.4808	1.4127	NA
	Corn - Soybeans	NA	1.1151	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-2

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "B"

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0535	1.0083	NA
	Rice - Soybeans/Wheat - Soybeans	1.0094	.9726	NA
	Soybeans - Soybeans/Wheat	1.2991	1.1872	NA
	Cotton - Soybeans	NA	.8798	NA
	Grain Sorghum - Soybeans	1.7424	1.6325	NA
	Corn - Soybeans	NA	1.0198	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.2708
	Cotton - Soybeans	NA	NA	.9410
	Grain Soybean - Soybeans	NA	NA	1.7123
	Corn - Soybeans	NA	NA	1.1915
3	Rice - Soybeans - Soybeans	1.0924	1.0618	NA
	Rice - Soybeans/Wheat - Soybeans	1.0266	.9991	NA
	Soybeans - Soybeans/Wheat	1.2657	1.1879	NA
	Grain Sorghum - Soybeans	1.7025	1.6280	NA
	Corn - Soybeans	NA	1.0377	NA
4	Rice - Soybeans - Soybeans	NA	1.0087	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9562	NA
	Soybeans - Soybeans/Wheat	NA	1.0241	NA
	Cotton - Soybeans	NA	1.0179	NA
	Grain Sorghum - Soybeans	NA	1.5313	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1255
	Cotton - Soybeans	NA	NA	1.0707
	Grain Sorghum - Soybeans	NA	NA	1.6160
6	Rice - Soybeans - Soybeans	NA	1.0624	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9900	NA
	Soybeans - Soybeans/Wheat	NA	1.0784	NA
	Grain Sorghum - Soybeans	NA	1.5995	NA
7	Soybeans - Soybeans/Wheat	1.0120	.9290	NA
	Cotton - Soybeans	NA	.7414	NA
	Grain Sorgum - Soybeans	1.3820	1.2979	NA
	Corn - Soybeans	NA	1.0004	NA

APPENDIX TABLE A-2 (Cont.)

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0545
	Cotton - Soybeans	NA	NA	.8285
	Grain Sorghum - Soybeans	NA	NA	1.4509
	Corn - Soybeans	NA	NA	1.1778
9	Soybeans - Soybeans/Wheat	1.0732	1.0073	NA
	Grain Sorghum - Soybeans	1.4707	1.4033	NA
	Corn - Soybeans	NA	1.1115	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-3

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "C"

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0924	1.0485	NA
	Rice - Soybeans/Wheat - Soybeans	1.0612	1.0214	NA
	Soybeans - Soybeans/Wheat	1.1996	1.1019	NA
	Cotton - Soybeans	NA	.8379	NA
	Grain Sorghum - Soybeans	1.5894	1.4938	NA
	Corn - Soybeans	NA	.9249	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.2584
	Cotton - Soybeans	NA	NA	.9451
	Grain Soybean - Soybeans	NA	NA	1.6799
	Corn - Soybeans	NA	NA	1.1646
3	Rice - Soybeans - Soybeans	1.0939	1.0553	NA
	Rice - Soybeans/Wheat - Soybeans	1.0377	1.0044	NA
	Soybeans - Soybeans/Wheat	1.1297	1.0554	NA
	Grain Sorghum - Soybeans	1.5052	1.4330	NA
	Corn - Soybeans	NA	.9083	NA
4	Rice - Soybeans - Soybeans	NA	1.0308	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9867	NA
	Soybeans - Soybeans/Wheat	NA	.9436	NA
	Cotton - Soybeans	NA	.9583	NA
	Grain Sorghum - Soybeans	NA	1.3858	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1126
	Cotton - Soybeans	NA	NA	1.0740
	Grain Sorghum - Soybeans	NA	NA	1.5849
6	Rice - Soybeans - Soybeans	NA	1.0935	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0276	NA
	Soybeans - Soybeans/Wheat	NA	1.0028	NA
	Grain Sorghum - Soybeans	NA	1.4754	NA
7	Soybeans - Soybeans/Wheat	1.0075	.9288	NA
	Cotton - Soybeans	NA	.7494	NA
	Grain Sorgum - Soybeans	1.3716	1.2991	NA
	Corn - Soybeans	NA	.9801	NA

APPENDIX TABLE A-3 (Cont.)

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0474
	Cotton - Soybeans	NA	NA	.8315
	Grain Sorghum - Soybeans	NA	NA	1.4327
	Corn - Soybeans	NA	NA	1.1552
9	Soybeans - Soybeans/Wheat	1.0751	1.0036	NA
	Grain Sorghum - Soybeans	1.4735	1.4013	NA
	Corn - Soybeans	NA	1.0931	NA

NA - Not applicable to soil group and crop rotation.

APPDENIX TABLE A-4

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "D"

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0423	1.0038	NA
	Rice - Soybeans/Wheat - Soybeans	1.0036	.9691	NA
	Soybeans - Soybeans/Wheat	1.3295	1.2198	NA
	Cotton - Soybeans	NA	.8971	NA
	Grain Sorghum - Soybeans	1.7926	1.6844	NA
	Corn - Soybeans	NA	1.0356	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.2500
	Cotton - Soybeans	NA	NA	.9249
	Grain Soybean - Soybeans	NA	NA	1.6925
	Corn - Soybeans	NA	NA	1.1627
3	Rice - Soybeans - Soybeans	1.0872	1.0516	NA
	Rice - Soybeans/Wheat - Soybeans	1.0217	.9913	NA
	Soybeans - Soybeans/Wheat	1.2875	1.2013	NA
	Grain Sorghum - Soybeans	1.7412	1.6573	NA
	Corn - Soybeans	NA	1.0457	NA
4	Rice - Soybeans - Soybeans	NA	1.0107	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9583	NA
	Soybeans - Soybeans/Wheat	NA	1.0567	NA
	Cotton - Soybeans	NA	1.0380	NA
	Grain Sorghum - Soybeans	NA	1.5779	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1060
	Cotton - Soybeans	NA	NA	1.0523
	Grain Sorghum - Soybeans	NA	NA	1.5970
6	Rice - Soybeans - Soybeans	NA	1.0585	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9871	NA
	Soybeans - Soybeans/Wheat	NA	1.1003	NA
	Grain Sorghum - Soybeans	NA	1.6361	NA
7	Soybeans - Soybeans/Wheat	1.0040	.9255	NA
	Cotton - Soybeans	NA	.7369	NA
	Grain Sorgum - Soybeans	1.3743	1.2945	NA
	Corn - Soybeans	NA	.9840	NA

APPENDIX TABLE A-4 (Cont.)

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0397
	Cotton - Soybeans	NA	NA	.8160
	Grain Sorghum - Soybeans	NA	NA	1.4369
	Corn - Soybeans	NA	NA	1.1535
9	Soybeans - Soybeans/Wheat	1.0665	.9957	NA
	Grain Sorghum - Soybeans	1.4643	1.3935	NA
	Corn - Soybeans	NA	1.0924	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-5

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "E"

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9745	.9359	NA
	Rice - Soybeans/Wheat - Soybeans	.9933	.9564	NA
	Soybeans - Soybeans/Wheat	1.0386	.9564	NA
	Cotton - Soybeans	NA	.8778	NA
	Grain Sorghum - Soybeans	1.1968	1.1300	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1412
	Cotton - Soybeans	NA	NA	1.0239
	Grain Soybean - Soybeans	NA	NA	1.2885
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0184	.9795	NA
	Rice - Soybeans/Wheat - Soybeans	1.0057	.9696	NA
	Soybeans - Soybeans/Wheat	1.0387	.9622	NA
	Grain Sorghum - Soybeans	1.2302	1.1675	NA
	Corn - Soybeans	NA		NA
4	Rice - Soybeans - Soybeans	NA	.9407	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9438	NA
	Soybeans - Soybeans/Wheat	NA	.8344	NA
	Cotton - Soybeans	NA	1.0522	NA
	Grain Sorghum - Soybeans	NA	1.1023	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0501
	Cotton - Soybeans	NA	NA	1.1755
	Grain Sorghum - Soybeans	NA	NA	1.2800
6	Rice - Soybeans - Soybeans	NA	1.0376	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0088	NA
	Soybeans - Soybeans/Wheat	NA	.9181	NA
	Grain Sorghum - Soybeans	NA	1.2574	NA
7	Soybeans - Soybeans/Wheat	.9143	.8386	NA
	Cotton - Soybeans	NA	.8071	NA
	Grain Sorgum - Soybeans	1.1144	1.0489	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-5 (Cont.)

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9689
	Cotton - Soybeans	NA	NA	.9126
	Grain Sorghum - Soybeans	NA	NA	1.1716
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9951	.9192	NA
	Grain Sorghum - Soybeans	1.2364	1.1697	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-6

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "F"

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9599	.9250	NA
	Rice - Soybeans/Wheat - Soybeans	.9632	.9304	NA
	Soybeans - Soybeans/Wheat	1.1743	1.0780	NA
	Cotton - Soybeans	NA	.9365	NA
	Grain Sorghum - Soybeans	1.3996	1.3213	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1151
	Cotton - Soybeans	NA	NA	.9795
	Grain Soybean - Soybeans	NA	NA	1.2867
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0181	.9813	NA
	Rice - Soybeans/Wheat - Soybeans	.9914	.9578	NA
	Soybeans - Soybeans/Wheat	1.1773	1.0858	NA
	Grain Sorghum - Soybeans	1.4284	1.3526	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9194	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9098	NA
	Soybeans - Soybeans/Wheat	NA	.9223	NA
	Cotton - Soybeans	NA	1.0571	NA
	Grain Sorghum - Soybeans	NA	1.2469	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0129
	Cotton - Soybeans	NA	NA	1.1151
	Grain Sorghum - Soybeans	NA	NA	1.2549
6	Rice - Soybeans - Soybeans	NA	.9847	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9482	NA
	Soybeans - Soybeans/Wheat	NA	.9680	NA
	Grain Sorghum - Soybeans	NA	1.3421	NA
7	Soybeans - Soybeans/Wheat	.9016	.8272	NA
	Cotton - Soybeans	NA	.7800	NA
	Grain Sorgum - Soybeans	1.1086	1.0444	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-6 (Cont.)

Soil Group	Crop Rotation	Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9414
	Cotton - Soybeans	NA	NA	.8731
	Grain Sorghum - Soybeans	NA	NA	1.1539
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9839	.9078	NA
	Grain Sorghum - Soybeans	1.2275	1.1612	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-7

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situtation "G"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9617	.9287	NA
	Rice - Soybeans/Wheat - Soybeans	.9840	.9509	NA
	Soybeans - Soybeans/Wheat	1.0841	1.0035	NA
	Cotton - Soybeans	NA	.9058	NA
	Grain Sorghum - Soybeans	1.2675	1.2033	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1095
	Cotton - Soybeans	NA	NA	.9975
	Grain Soybean - Soybeans	NA	NA	1.2602
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0073	.9637	NA
	Rice - Soybeans/Wheat - Soybeans	.9979	.9572	NA
	Soybeans - Soybeans/Wheat	1.0717	.9820	NA
	Grain Sorghum - Soybeans	1.2814	1.2087	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9138	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9193	NA
	Soybeans - Soybeans/Wheat	NA	.8498	NA
	Cotton - Soybeans	NA	1.0078	NA
	Grain Sorghum - Soybeans	NA	1.1208	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0198
	Cotton - Soybeans	NA	NA	1.1455
	Grain Sorghum - Soybeans	NA	NA	1.2522
6	Rice - Soybeans - Soybeans	NA	.9977	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9736	NA
	Soybeans - Soybeans/Wheat	NA	.9132	NA
	Grain Sorghum - Soybeans	NA	1.2525	NA
7	Soybeans - Soybeans/Wheat	.9023	.8335	NA
	Cotton - Soybeans	NA	.7998	NA
	Grain Sorgum - Soybeans	1.1035	1.0442	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-7 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
	Soybeans - Soybeans/Wheat	NA	NA	.9470
8	Cotton - Soybeans	NA	NA	.8924
	Grain Sorghum - Soybeans	NA	NA	1.1518
	Corn - Soybeans	NA	NA	NA
	Soybeans - Soybeans/Wheat	.9851	.9022	NA
9	Grain Sorghum - Soybeans	1.2274	1.1558	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-8

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "H"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9497	.9193	NA
	Rice - Soybeans/Wheat - Soybeans	.9558	.9260	NA
	Soybeans - Soybeans/Wheat	1.2138	1.1206	NA
	Cotton - Soybeans	NA		NA
	Grain Sorghum - Soybeans	1.4604	1.3845	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0874
	Cotton - Soybeans	NA	NA	.9563
	Grain Soybean - Soybeans	NA	NA	1.2623
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0092	.9685	NA
	Rice - Soybeans/Wheat - Soybeans	.9851	.9479	NA
	Soybeans - Soybeans/Wheat	1.2060	1.1030	NA
	Grain Sorghum - Soybeans	1.4724	1.3881	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9219	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9124	NA
	Soybeans - Soybeans/Wheat	NA	.9625	NA
	Cotton - Soybeans	NA	1.0854	NA
	Grain Sorghum - Soybeans	NA	1.3044	NA
5	Soybeans - Soybeans/Wheat	NA	NA	.9865
	Cotton - Soybeans	NA	NA	1.0888
	Grain Sorghum - Soybeans	NA	NA	1.2310
6	Rice - Soybeans - Soybeans	NA	.9798	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9447	NA
	Soybeans - Soybeans/Wheat	NA	.9953	NA
	Grain Sorghum - Soybeans	NA	1.3859	NA
7	Soybeans - Soybeans/Wheat	.8912	.8227	NA
	Cotton - Soybeans	NA	.7735	NA
	Grain Sorgum - Soybeans	1.0993	1.0402	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-8 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9223
	Cotton - Soybeans	NA	NA	.8544
	Grain Sorghum - Soybeans	NA	NA	1.1368
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9751	.8930	NA
	Grain Sorghum - Soybeans	1.2197	1.1493	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-9

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "I"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0264	.9816	NA
	Rice - Soybeans/Wheat - Soybeans	1.0248	.9840	NA
	Soybeans - Soybeans/Wheat	1.0682	.9769	NA
	Cotton - Soybeans	NA	.8441	NA
	Grain Sorghum - Soybeans	1.0572	.9916	NA
	Corn - Soybeans	NA	.7880	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0919
	Cotton - Soybeans	NA	NA	.9634
	Grain Soybean - Soybeans	NA	NA	1.1104
	Corn - Soybeans	NA	NA	.9810
3	Rice - Soybeans - Soybeans	1.0455	1.0132	NA
	Rice - Soybeans/Wheat - Soybeans	1.0422	1.0125	NA
	Soybeans - Soybeans/Wheat	1.1000	1.0357	NA
	Grain Sorghum - Soybeans	1.0759	1.0324	NA
	Corn - Soybeans	NA	.8313	NA
4	Rice - Soybeans - Soybeans	NA	.9584	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9645	NA
	Soybeans - Soybeans/Wheat	NA	.9360	NA
	Cotton - Soybeans	NA	.9385	NA
	Grain Sorghum - Soybeans	NA	.9594	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0639
	Cotton - Soybeans	NA	NA	1.0948
	Grain Sorghum - Soybeans	NA	NA	1.0906
6	Rice - Soybeans - Soybeans	NA	.9996	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0013	NA
	Soybeans - Soybeans/Wheat	NA	1.0068	NA
	Grain Sorghum - Soybeans	NA	1.0138	NA
7	Soybeans - Soybeans/Wheat	1.0168	.9328	NA
	Cotton - Soybeans	NA	.7501	NA
	Grain Sorgum - Soybeans	1.0178	.9559	NA
	Corn - Soybeans	NA	.9193	NA

APPENDIX TABLE A-9 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0344
	Cotton - Soybeans	NA	NA	.8457
	Grain Sorghum - Soybeans	NA	NA	1.0534
	Corn - Soybeans	NA	NA	1,0661
9	Soybeans - Soybeans/Wheat	1.0828	1.0169	NA
	Grain Sorghum - Soybeans	1.0623	1.0167	NA
	Corn - Soybeans	NA	.9982	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-10

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "J"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0090	.9687	NA
	Rice - Soybeans/Wheat - Soybeans	1.0094	.9726	NA
	Soybeans - Soybeans/Wheat	1.0533	.9638	NA
	Cotton - Soybeans	NA	.8335	NA
	Grain Sorghum - Soybeans	1.0428	.9790	NA
	Corn - Soybeans	NA	.7670	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0602
	Cotton - Soybeans	NA	NA	.9410
	Grain Soybean - Soybeans	NA	NA	1.0820
	Corn - Soybeans	NA	NA	.9396
3	Rice - Soybeans - Soybeans	1.0276	.9978	NA
	Rice - Soybeans/Wheat - Soybeans	1.0266	.9991	NA
	Soybeans - Soybeans/Wheat	1.0875	1.0230	NA
	Grain Sorghum - Soybeans	1.0633	1.0199	NA
	Corn - Soybeans	NA	.8124	NA
4	Rice - Soybeans - Soybeans	NA	.9491	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9562	NA
	Soybeans - Soybeans/Wheat	NA	.9273	NA
	Cotton - Soybeans	NA	.9285	NA
	Grain Sorghum - Soybeans	NA	.9499	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0364
	Cotton - Soybeans	NA	NA	1.0707
	Grain Sorghum - Soybeans	NA	NA	1.0646
6	Rice - Soybeans - Soybeans	NA	.9865	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9900	NA
	Soybeans - Soybeans/Wheat	NA	.9971	NA
	Grain Sorghum - Soybeans	NA	1.0032	NA
7	Soybeans - Soybeans/Wheat	1.0062	.9237	NA
	Cotton - Soybeans	NA	.7417	NA
	Grain Sorgum - Soybeans	1.0071	.9467	NA
	Corn - Soybeans	NA	.9006	NA

APPENDIX TABLE A-10 (Cont)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0126
	Cotton - Soybeans	NA	NA	.8285
	Grain Sorghum - Soybeans	NA	NA	1.0335
	Corn - Soybeans	NA	NA	1.0323
9	Soybeans - Soybeans/Wheat	1.0732	1.0073	NA
	Grain Sorghum - Soybeans	1.0520	1.0067	NA
	Corn - Soybeans	NA	.9808	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-11

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "K"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0162	.9759	NA
	Rice - Soybeans/Wheat - Soybeans	1.0176	.9797	NA
	Soybeans - Soybeans/Wheat	1.0560	.9717	NA
	Cotton - Soybeans	NA	.8379	NA
	Grain Sorghum - Soybeans	1.0456	.9866	NA
	Corn - Soybeans	NA	.7683	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0680
	Cotton - Soybeans	NA	NA	.9451
	Grain Soybean - Soybeans	NA	NA	1.0875
	Corn - Soybeans	NA	NA	.9478
3	Rice - Soybeans - Soybeans	1.0367	1.0005	NA
	Rice - Soybeans/Wheat - Soybeans	1.0361	1.0028	NA
	Soybeans - Soybeans/Wheat	1.0902	1.0189	NA
	Grain Sorghum - Soybeans	1.0667	1.0182	NA
	Corn - Soybeans	NA	.8091	NA
4	Rice - Soybeans - Soybeans	NA	.9609	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9670	NA
	Soybeans - Soybeans/Wheat	NA	.9436	NA
	Cotton - Soybeans	NA	.9370	NA
	Grain Sorghum - Soybeans	NA	.9469	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0415
	Cotton - Soybeans	NA	NA	1.0740
	Grain Sorghum - Soybeans	NA	NA	1.0686
6	Rice - Soybeans - Soybeans	NA	.9947	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9978	NA
	Soybeans - Soybeans/Wheat	NA	1.0028	NA
	Grain Sorghum - Soybeans	NA	1.0098	NA
7	Soybeans - Soybeans/Wheat	1.0075	.9288	NA
	Cotton - Soybeans	NA	.7449	NA
	Grain Sorgum - Soybeans	1.0089	.9520	NA
	Corn - Soybeans	NA	.9005	NA

APPENDIX TABLE A-11 (Cont)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0174
	Cotton - Soybeans	NA	NA	.8315
	Grain Sorghum - Soybeans	NA	NA	1.0372
	Corn - Soybeans	NA	NA	1.0382
9	Soybeans - Soybeans/Wheat	1.0751	1.0036	NA
	Grain Sorghum - Soybeans	1.0549	1.0054	NA
	Corn - Soybeans	NA	.9762	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-12

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "L"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0009	.9642	NA
	Rice - Soybeans/Wheat - Soybeans	1.0036	.9691	NA
	Soybeans - Soybeans/Wheat	1.0427	.9592	NA
	Cotton - Soybeans	NA	.8280	NA
	Grain Sorghum - Soybeans	1.0328	.9746	NA
	Corn - Soybeans	NA	.7499	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0394
	Cotton - Soybeans	NA	NA	.9249
	Grain Soybean - Soybeans	NA	NA	1.0623
	Corn - Soybeans	NA	NA	.9107
3	Rice - Soybeans - Soybeans	1.0206	.9876	NA
	Rice - Soybeans/Wheat - Soybeans	1.0217	.9913	NA
	Soybeans - Soybeans/Wheat	1.0791	1.0084	NA
	Grain Sorghum - Soybeans	1.0554	1.0076	NA
	Corn - Soybeans	NA	.7931	NA
4	Rice - Soybeans - Soybeans	NA	.9511	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9583	NA
	Soybeans - Soybeans/Wheat	NA	.9339	NA
	Cotton - Soybeans	NA	.9271	NA
	Grain Sorghum - Soybeans	NA	.9547	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0169
	Cotton - Soybeans	NA	NA	1.0523
	Grain Sorghum - Soybeans	NA	NA	1.0456
6	Rice - Soybeans - Soybeans	NA	.9826	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9871	NA
	Soybeans - Soybeans/Wheat	NA	.9936	NA
	Grain Sorghum - Soybeans	NA	.9997	NA
7	Soybeans - Soybeans/Wheat	.9982	.9202	NA
	Cotton - Soybeans	NA	.7369	NA
	Grain Sorgum - Soybeans	.9994	.9434	NA
	Corn - Soybeans	NA	.8842	NA

APPENDIX TABLE A-12 (Cont)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9979
	Cotton - Soybeans	NA	NA	.8160
	Grain Sorghum - Soybeans	NA	NA	1.0196
	Corn - Soybeans	NA	NA	1.0080
9	Soybeans - Soybeans/Wheat	1.0665	.9957	NA
	Grain Sorghum - Soybeans	1.0457	.9969	NA
	Corn - Soybeans	NA	.9616	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-13

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "M"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9745	.9359	NA
	Rice - Soybeans/Wheat - Soybeans	.9757	.9395	NA
	Soybeans - Soybeans/Wheat	.9529	.8767	NA
	Cotton - Soybeans	NA	.8410	NA
	Grain Sorghum - Soybeans	1.0787	1.0191	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1412
	Cotton - Soybeans	NA	NA	1.0239
	Grain Soybean - Soybeans	NA	NA	1.2885
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0058	.9675	NA
	Rice - Soybeans/Wheat - Soybeans	1.0057	.9696	NA
	Soybeans - Soybeans/Wheat	1.0161	.9418	NA
	Grain Sorghum - Soybeans	1.0165	.9678	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9081	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9160	NA
	Soybeans - Soybeans/Wheat	NA	.8344	NA
	Cotton - Soybeans	NA	.8885	NA
	Grain Sorghum - Soybeans	NA		NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0501
	Cotton - Soybeans	NA	NA	1.1483
	Grain Sorghum - Soybeans	NA	NA	1.1718
6	Rice - Soybeans - Soybeans	NA	.9526	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9577	NA
	Soybeans - Soybeans/Wheat	NA	.9181	NA
	Grain Sorghum - Soybeans	NA	.9493	NA
7	Soybeans - Soybeans/Wheat	.9143	.8386	NA
	Cotton - Soybeans	NA	.7473	NA
	Grain Sorgum - Soybeans	.9476	.8927	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-13 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9689
	Cotton - Soybeans	NA	NA	.8758
	Grain Sorghum - Soybeans	NA	NA	1.0102
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9951	.9192	NA
	Grain Sorghum - Soybeans	1.0003	.9489	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-14

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "N"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9599	.9250	NA
	Rice - Soybeans/Wheat - Soybeans	.9626	.9298	NA
	Soybeans - Soybeans/Wheat	.9300	.8555	NA
	Cotton - Soybeans	NA	.8261	NA
	Grain Sorghum - Soybeans	.9597	.9078	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0067
	Cotton - Soybeans	NA	NA	.9795
	Grain Soybean - Soybeans	NA	NA	1.1107
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	.9896	.9541	NA
	Rice - Soybeans/Wheat - Soybeans	.9914	.9578	NA
	Soybeans - Soybeans/Wheat	1.0012	.9265	NA
	Grain Sorghum - Soybeans	1.0032	.9545	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9010	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9098	NA
	Soybeans - Soybeans/Wheat	NA	.8232	NA
	Cotton - Soybeans	NA	.9051	NA
	Grain Sorghum - Soybeans	NA	.8783	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0129
	Cotton - Soybeans	NA	NA	1.1137
	Grain Sorghum - Soybeans	NA	NA	1.0531
6	Rice - Soybeans - Soybeans	NA	.9418	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9482	NA
	Soybeans - Soybeans/Wheat	NA	.9068	NA
	Grain Sorghum - Soybeans	NA	.9382	NA
7	Soybeans - Soybeans/Wheat	.9016	.8272	NA
	Cotton - Soybeans	NA	.7351	NA
	Grain Sorgum - Soybeans	.9365	.8829	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-14 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9414
	Cotton - Soybeans	NA	NA	.8515
	Grain Sorghum - Soybeans	NA	NA	.9873
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9839	.9078	NA
	Grain Sorghum - Soybeans	.9897	.9386	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-15

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "O"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9617	.9287	NA
	Rice - Soybeans/Wheat - Soybeans	.9664	.9340	NA
	Soybeans - Soybeans/Wheat	.9371	.8698	NA
	Cotton - Soybeans	NA	.8321	NA
	Grain Sorghum - Soybeans	1.0647	1.0129	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1095
	Cotton - Soybeans	NA	NA	.9975
	Grain Soybean - Soybeans	NA	NA	1.2602
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	.9947	.9517	NA
	Rice - Soybeans/Wheat - Soybeans	.9979	.9572	NA
	Soybeans - Soybeans/Wheat	1.0033	.9202	NA
	Grain Sorghum - Soybeans	1.0052	.9506	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9112	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9193	NA
	Soybeans - Soybeans/Wheat	NA	.8444	NA
	Cotton - Soybeans	NA	.9168	NA
	Grain Sorghum - Soybeans	NA	.8953	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0198
	Cotton - Soybeans	NA	NA	1.1183
	Grain Sorghum - Soybeans	NA	NA	1.1440
6	Rice - Soybeans - Soybeans	NA	.9466	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9533	NA
	Soybeans - Soybeans/Wheat	NA	.9132	NA
	Grain Sorghum - Soybeans	NA	.9444	NA
7	Soybeans - Soybeans/Wheat	.9023	.8335	NA
	Cotton - Soybeans	NA	.7399	NA
	Grain Sorgum - Soybeans	.9367	.8879	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-15 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9470
	Cotton - Soybeans	NA	NA	.8556
	Grain Sorghum - Soybeans	NA	NA	.9904
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9851	.9022	NA
	Grain Sorghum - Soybeans	.9912	.9351	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-16

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "P"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9497	.9193	NA
	Rice - Soybeans/Wheat - Soybeans	.9552	.9254	NA
	Soybeans - Soybeans/Wheat	.9162	.8496	NA
	Cotton - Soybeans	NA	.8183	NA
	Grain Sorghum - Soybeans	.9476	.9025	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	.9791
	Cotton - Soybeans	NA	NA	.9563
	Grain Soybean - Soybeans	NA	NA	1.0863
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	.9808	.9414	NA
	Rice - Soybeans/Wheat - Soybeans	.9851	.9479	NA
	Soybeans - Soybeans/Wheat	.9832	.9077	NA
	Grain Sorghum - Soybeans	.9935	.9897	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9036	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9124	NA
	Soybeans - Soybeans/Wheat	NA	.8319	NA
	Cotton - Soybeans	NA	.9032	NA
	Grain Sorghum - Soybeans	NA	.8842	NA
5	Soybeans - Soybeans/Wheat	NA	NA	.9865
	Cotton - Soybeans	NA	NA	1.0873
	Grain Sorghum - Soybeans	NA	NA	1.0292
6	Rice - Soybeans - Soybeans	NA	.9369	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9447	NA
	Soybeans - Soybeans/Wheat	NA	.9025	NA
	Grain Sorghum - Soybeans	NA	.9340	NA
7	Soybeans - Soybeans/Wheat	.8912	.8227	NA
	Cotton - Soybeans	NA	.7287	NA
	Grain Sorgum - Soybeans	.9271	.8788	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-16 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9223
	Cotton - Soybeans	NA	NA	.8337
	Grain Sorghum - Soybeans	NA	NA	.9702
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9751	.8930	NA
	Grain Sorghum - Soybeans	.9820	.9267	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-17

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "Q"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0430	.9987	NA
	Rice - Soybeans/Wheat - Soybeans	1.0394	.9992	NA
	Soybeans - Soybeans/Wheat	1.0905	.9998	NA
	Cotton - Soybeans	NA	.8608	NA
	Grain Sorghum - Soybeans	1.0955	1.0292	NA
	Corn - Soybeans	NA	.8198	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1201
	Cotton - Soybeans	NA	NA	.9857
	Grain Soybean - Soybeans	NA	NA	1.2583
	Corn - Soybeans	NA	NA	1.0213
3	Rice - Soybeans - Soybeans	1.0600	1.0309	NA
	Rice - Soybeans/Wheat - Soybeans	1.0547	1.0277	NA
	Soybeans - Soybeans/Wheat	1.1177	1.0584	NA
	Grain Sorghum - Soybeans	1.0910	1.0516	NA
	Corn - Soybeans	NA	.8604	NA
4	Rice - Soybeans - Soybeans	NA	.9722	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9767	NA
	Soybeans - Soybeans/Wheat	NA	.9509	NA
	Cotton - Soybeans	NA	.9525	NA
	Grain Sorghum - Soybeans	NA	.9736	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0885
	Cotton - Soybeans	NA	NA	1.1171
	Grain Sorghum - Soybeans	NA	NA	1.1155
6	Rice - Soybeans - Soybeans	NA	1.0146	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0143	NA
	Soybeans - Soybeans/Wheat	NA	1.0237	NA
	Grain Sorghum - Soybeans	NA	1.0295	NA
7	Soybeans - Soybeans/Wheat	1.0337	.9502	NA
	Cotton - Soybeans	NA	.7638	NA
	Grain Sorgum - Soybeans	1.0324	.9710	NA
	Corn - Soybeans	NA	.9496	NA

APPENDIX TABLE A-17 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0544
	Cotton - Soybeans	NA	NA	.8629
	Grain Sorghum - Soybeans	NA	NA	1.0708
	Corn - Soybeans	NA	NA	1.0999
9	Soybeans - Soybeans/Wheat	1.0968	1.0348	NA
	Grain Sorghum - Soybeans	1.0744	1.0320	NA
	Corn - Soybeans	NA	1.0271	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-18

COST/BENEFIT RATIOS
. FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "R"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0222	.9824	NA
	Rice - Soybeans/Wheat - Soybeans	1.0210	.9847	NA
	Soybeans - Soybeans/Wheat	1.0727	.9837	NA
	Cotton - Soybeans	NA	.8481	NA
	Grain Sorghum - Soybeans	1.0591	.9959	NA
	Corn - Soybeans	NA	.7947	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0848
	Cotton - Soybeans	NA	NA	.9607
	Grain Soybean - Soybeans	NA	NA	1.1032
	Corn - Soybeans	NA	NA	.9747
3	Rice - Soybeans - Soybeans	1.0392	1.0120	NA
	Rice - Soybeans/Wheat - Soybeans	1.0366	1.0113	NA
	Soybeans - Soybeans/Wheat	1.1029	1.0427	NA
	Grain Sorghum - Soybeans	1.0763	1.0364	NA
	Corn - Soybeans	NA	.8378	NA
4	Rice - Soybeans - Soybeans	NA	.9602	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9661	NA
	Soybeans - Soybeans/Wheat	NA	.9403	NA
	Cotton - Soybeans	NA	.9408	NA
	Grain Sorghum - Soybeans	NA	.9622	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0578
	Cotton - Soybeans	NA	NA	1.0903
	Grain Sorghum - Soybeans	NA	NA	1.0844
6	Rice - Soybeans - Soybeans	NA	.9987	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0005	NA
	Soybeans - Soybeans/Wheat	NA	1.0118	NA
	Grain Sorghum - Soybeans	NA	1.0167	NA
7	Soybeans - Soybeans/Wheat	1.0209	.9389	NA
	Cotton - Soybeans	NA	.7535	NA
	Grain Sorgum - Soybeans	1.0179	.9598	NA
	Corn - Soybeans	NA	.9270	NA

APPENDIX TABLE A-18 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0301
	Cotton - Soybeans	NA	NA	.8437
	Grain Sorghum - Soybeans	NA	NA	1.0486
	Corn - Soybeans	NA	NA	1.0618
9	Soybeans - Soybeans/Wheat	1.0853	1.0228	NA
	Grain Sorghum - Soybeans	1.0624	1.0199	NA
	Corn - Soybeans	NA	1.0060	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-19

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "S"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0312	.9920	NA
	Rice - Soybeans/Wheat - Soybeans	1.0307	.9940	NA
	Soybeans - Soybeans/Wheat	1.0762	.9937	NA
	Cotton - Soybeans	NA	.8538	NA
	Grain Sorghum - Soybeans	1.0825	1.0236	NA
	Corn - Soybeans	NA	.7977	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0912
	Cotton - Soybeans	NA	NA	.9644
	Grain Soybean - Soybeans	NA	NA	1.2317
	Corn - Soybeans	NA	NA	.9817
3	Rice - Soybeans - Soybeans	1.0499	1.0148	NA
	Rice - Soybeans/Wheat - Soybeans	1.0475	1.0152	NA
	Soybeans - Soybeans/Wheat	1.1063	1.0367	NA
	Grain Sorghum - Soybeans	1.0806	1.0335	NA
	Corn - Soybeans	NA	.8343	NA
4	Rice - Soybeans - Soybeans	NA	.9763	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9805	NA
	Soybeans - Soybeans/Wheat	NA	.9617	NA
	Cotton - Soybeans	NA	.9519	NA
	Grain Sorghum - Soybeans	NA	.9819	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0613
	Cotton - Soybeans	NA	NA	1.0928
	Grain Sorghum - Soybeans	NA	NA	1.0898
6	Rice - Soybeans - Soybeans	NA	1.0089	NA
	Rice - Soybeans/Wheat - Soybeans	NA	1.0101	NA
	Soybeans - Soybeans/Wheat	NA	1.0191	NA
	Grain Sorghum - Soybeans	NA	1.0249	NA
7	Soybeans - Soybeans/Wheat	1.0228	.9456	NA
	Cotton - Soybeans	NA	.7581	NA
	Grain Sorgum - Soybeans	1.0223	.9667	NA
	Corn - Soybeans	NA	.9285	NA

APPENDIX TABLE A- 19 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	1.0338
	Cotton - Soybeans	NA	NA	.8465
	Grain Sorghum - Soybeans	NA	NA	1.0519
	Corn - Soybeans	NA	NA	1.0667
9	Soybeans - Soybeans/Wheat	1.0878	1.0177	NA
	Grain Sorghum - Soybeans	1.0661	1.0176	NA
	Corn - Soybeans	- NA	1.0012	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-20

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "T"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0128	.9771	NA
	Rice - Soybeans/Wheat - Soybeans	1.0141	.9805	NA
	Soybeans - Soybeans/Wheat	1.0602	.9783	NA
	Cotton - Soybeans	NA	.8420	NA
	Grain Sorghum - Soybeans	1.0479	.9910	NA
	Corn - Soybeans	NA	.7755	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.0596
	Cotton - Soybeans	NA	NA	.9419
	Grain Soybean - Soybeans	NA	NA	1.0802
	Corn - Soybeans	NA	NA	.9402
3	Rice - Soybeans - Soybeans	1.0312	.9991	NA
	Rice - Soybeans/Wheat - Soybeans	1.0308	.9692	NA
	Soybeans - Soybeans/Wheat	1.0930	1.0239	NA
	Grain Sorghum - Soybeans	1.0674	1.0208	NA
	Corn - Soybeans	NA	.8150	NA
4	Rice - Soybeans - Soybeans	NA	.9635	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9692	NA
	Soybeans - Soybeans/Wheat	NA	.9497	NA
	Cotton - Soybeans	NA	.9403	NA
	Grain Sorghum - Soybeans	NA	.9694	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0342
	Cotton - Soybeans	NA	NA	1.0689
	Grain Sorghum - Soybeans	NA	NA	1.0622
6	Rice - Soybeans - Soybeans	NA	.9941	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9971	NA
	Soybeans - Soybeans/Wheat	NA	1.0077	NA
	Grain Sorghum - Soybeans	NA	1.0128	NA
7	Soybeans - Soybeans/Wheat	1.0115	.9348	NA
	Cotton - Soybeans	NA	.7484	NA
	Grain Sorgum - Soybeans	1.0110	.9560	NA
	Corn - Soybeans	NA	.9807	NA

APPENDIX TABLE A-20 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
	Soybeans - Soybeans/Wheat	NA	NA	1.0122
8	Cotton - Soybeans	NA	NA	.8292
	Grain Sorghum - Soybeans	NA	NA	1.0323
	Corn - Soybeans	NA	NA	1.0328
	Soybeans - Soybeans/Wheat	1.0775	1.0080	NA
9	Grain Sorghum - Soybeans	1.0553	1.0075	NA
	Corn - Soybeans	NA	.9834	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-21

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "U"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.1233	1.0797	NA
	Rice - Soybeans/Wheat - Soybeans	1.1509	1.1091	NA
	Soybeans - Soybeans/Wheat	1.1577	1.0663	NA
	Cotton - Soybeans	NA	1.0126	NA
	Grain Sorghum - Soybeans	1.3260	1.2535	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.3540
	Cotton - Soybeans	NA	NA	1.2318
	Grain Soybean - Soybeans	NA	NA	1.5592
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0241	.9896	NA
	Rice - Soybeans/Wheat - Soybeans	1.0219	.9889	NA
	Soybeans - Soybeans/Wheat	1.0394	.9709	NA
	Grain Sorghum - Soybeans	1.1094	1.0606	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9831	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9997	NA
	Soybeans - Soybeans/Wheat	NA	.8540	NA
	Cotton - Soybeans	NA	1.0541	NA
	Grain Sorghum - Soybeans	NA	NA	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1527
	Cotton - Soybeans	NA	NA	1.3392
	Grain Sorghum - Soybeans	NA	NA	1.4109
6	Rice - Soybeans - Soybeans	NA	.9711	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9741	NA
	Soybeans - Soybeans/Wheat	NA	.9392	NA
	Grain Sorghum - Soybeans	NA	.9680	NA
7	Soybeans - Soybeans/Wheat	.9361	.8611	NA
	Cotton - Soybeans	NA	.8317	NA
	Grain Sorgum - Soybeans	1.0284	.9702	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-21 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9948
	Cotton - Soybeans	NA	NA	.9424
	Grain Sorghum - Soybeans	NA	NA	1.0926
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	1.0134	.9421	NA
	Grain Sorghum - Soybeans	1.0151	.9676	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-22

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "V"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9764	.9421	NA
	Rice - Soybeans/Wheat - Soybeans	.9774	.9454	NA
	Soybeans - Soybeans/Wheat	1.0078	.9294	NA
	Cotton - Soybeans	NA	.8906	NA
	Grain Sorghum - Soybeans	1.4420	1.0812	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1804
	Cotton - Soybeans	NA	NA	1.0833
	Grain Soybean - Soybeans	NA	NA	1.3441
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0043	.9718	NA
	Rice - Soybeans/Wheat - Soybeans	1.0043	.9734	NA
	Soybeans - Soybeans/Wheat	1.0214	.9518	NA
	Grain Sorghum - Soybeans	1.0191	.9745	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9150	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9225	NA
	Soybeans - Soybeans/Wheat	NA	.8403	NA
	Cotton - Soybeans	NA	.9302	NA
	Grain Sorghum - Soybeans	NA	.9109	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0419
	Cotton - Soybeans	NA	NA	1.1780
	Grain Sorghum - Soybeans	NA	NA	1.2177
6	Rice - Soybeans - Soybeans	NA	.9567	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9615	NA
	Soybeans - Soybeans/Wheat	NA	.9251	NA
	Grain Sorghum - Soybeans	NA	.9544	NA
7	Soybeans - Soybeans/Wheat	.9207	.8467	NA
	Cotton - Soybeans	NA	.7522	NA
	Grain Sorgum - Soybeans	.9518	.8988	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-22 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9639
	Cotton - Soybeans	NA	NA	.8731
	Grain Sorghum - Soybeans	NA	NA	1.0057
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9998	.9278	NA
	Grain Sorghum - Soybeans	1.0025	.9547	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-23

COST/BENEFIT RATIOS
FOR ALTERNATIVE IRRIGATION SYSTEMS
BY CROP ROTATION AND SOIL GROUP

Situation "W"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	1.0515	1.0169	NA
	Rice - Soybeans/Wheat - Soybeans	1.0865	1.0513	NA
	Soybeans - Soybeans/Wheat	1.1391	1.0583	NA
	Cotton - Soybeans	NA	1.0027	NA
	Grain Sorghum - Soybeans	1.3102	1.2466	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.3157
	Cotton - Soybeans	NA	NA	1.2011
	Grain Soybean - Soybeans	NA	NA	1.5262
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	1.0113	.9695	NA
	Rice - Soybeans/Wheat - Soybeans	1.0125	.9730	NA
	Soybeans - Soybeans/Wheat	1.0244	.9431	NA
	Grain Sorghum - Soybeans	1.0968	1.0387	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9448	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9643	NA
	Soybeans - Soybeans/Wheat	NA	.8682	NA
	Cotton - Soybeans	NA	1.0564	NA
	Grain Sorghum - Soybeans	NA	1.0643	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.1159
	Cotton - Soybeans	NA	NA	1.3042
	Grain Sorghum - Soybeans	NA	NA	1.3783
6	Rice - Soybeans - Soybeans	NA	.9642	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9687	NA
	Soybeans - Soybeans/Wheat	NA	.9334	NA
	Grain Sorghum - Soybeans	NA	.9626	NA
7	Soybeans - Soybeans/Wheat	.9221	.8550	NA
	Cotton - Soybeans	NA	.8236	NA
	Grain Sorgum - Soybeans	1.0162	.9649	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-23 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9682
	Cotton - Soybeans	NA	NA	.9189
	Grain Sorghum - Soybeans	NA	NA	1.0694
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	NA	.9203	NA
	Grain Sorghum - Soybeans	NA	.9500	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

APPENDIX TABLE A-24

COST/BENEFIT RATIOS FOR ALTERNATIVE IRRIGATION SYSTEMS BY CROP ROTATION AND SOIL GROUP

Situation "X"

Soil Group		Flood	Furrow	Center Pivot
1	Rice - Soybeans - Soybeans	.9646	.9355	NA
	Rice - Soybeans/Wheat - Soybeans	.9686	.9401	NA
	Soybeans - Soybeans/Wheat	.9916	.9224	NA
	Cotton - Soybeans	NA	.8818	NA
	Grain Sorghum - Soybeans	1.1284	1.0752	NA
	Corn - Soybeans	NA	NA	NA
2	Soybeans - Soybeans/Wheat	NA	NA	1.1469
	Cotton - Soybeans	NA	NA	1.0563
	Grain Soybean - Soybeans	NA	NA	1.3157
	Corn - Soybeans	NA	NA	NA
3	Rice - Soybeans - Soybeans	.9941	.9557	NA
	Rice - Soybeans/Wheat - Soybeans	.9968	.9606	NA
	Soybeans - Soybeans/Wheat	1.0084	.9276	NA
	Grain Sorghum - Soybeans	1.0083	.9557	NA
	Corn - Soybeans	NA	NA	NA
4	Rice - Soybeans - Soybeans	NA	.9192	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9265	NA
	Soybeans - Soybeans/Wheat	NA	.8527	NA
	Cotton - Soybeans	NA	.9295	NA
	Grain Sorghum - Soybeans	NA	.9198	NA
5	Soybeans - Soybeans/Wheat	NA	NA	1.0099
	Cotton - Soybeans	NA	NA	1.1473
	Grain Sorghum - Soybeans	NA	NA	1.1896
6	Rice - Soybeans - Soybeans	NA	.9511	NA
	Rice - Soybeans/Wheat - Soybeans	NA	.9572	NA
	Soybeans - Soybeans/Wheat	NA	.9201	NA
	Grain Sorghum - Soybeans	NA	.9497	NA
7	Soybeans - Soybeans/Wheat	.9085	.8415	NA
	Cotton - Soybeans	NA	.7451	NA
	Grain Sorgum - Soybeans	.9413	.8942	NA
	Corn - Soybeans	NA	NA	NA

APPENDIX TABLE A-24 (Cont.)

Soil Group		Flood	Furrow	Center Pivot
8	Soybeans - Soybeans/Wheat	NA	NA	.9408
	Cotton - Soybeans	NA	NA	.8524
	Grain Sorghum - Soybeans	NA	NA	.9857
	Corn - Soybeans	NA	NA	NA
9	Soybeans - Soybeans/Wheat	.9895	.9087	NA
	Grain Sorghum - Soybeans	.9938	.9396	NA
	Corn - Soybeans	NA	NA	NA

NA - Not applicable to soil group and crop rotation.

Figure A-1

POTENTIAL IRRIGATED CROPLAND
SITUATION A: 1985 BASELINE CROP PRICES.
NORMAL PRODUCTION COSTS, HIGH YIELDS.
DIESEL POWER, 10% DISCOUNT RATE

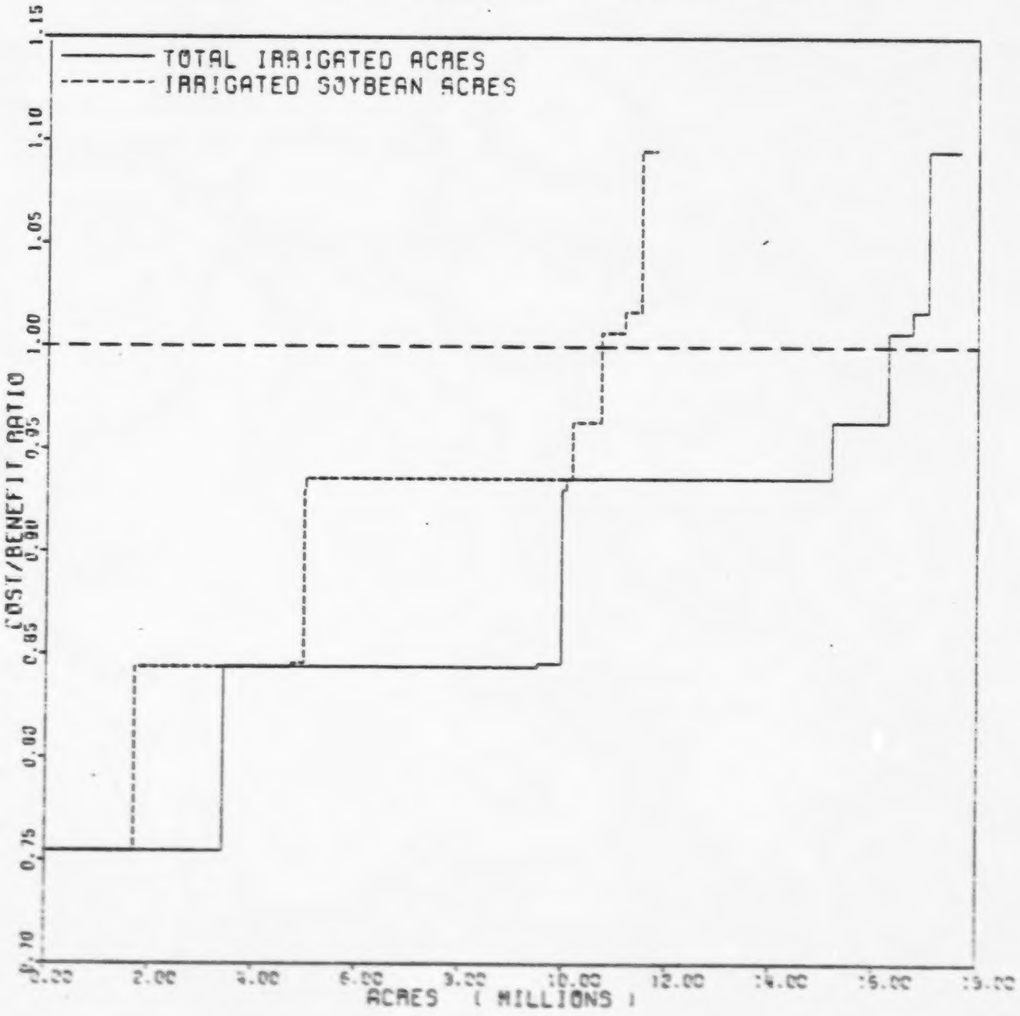

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Figure A-2

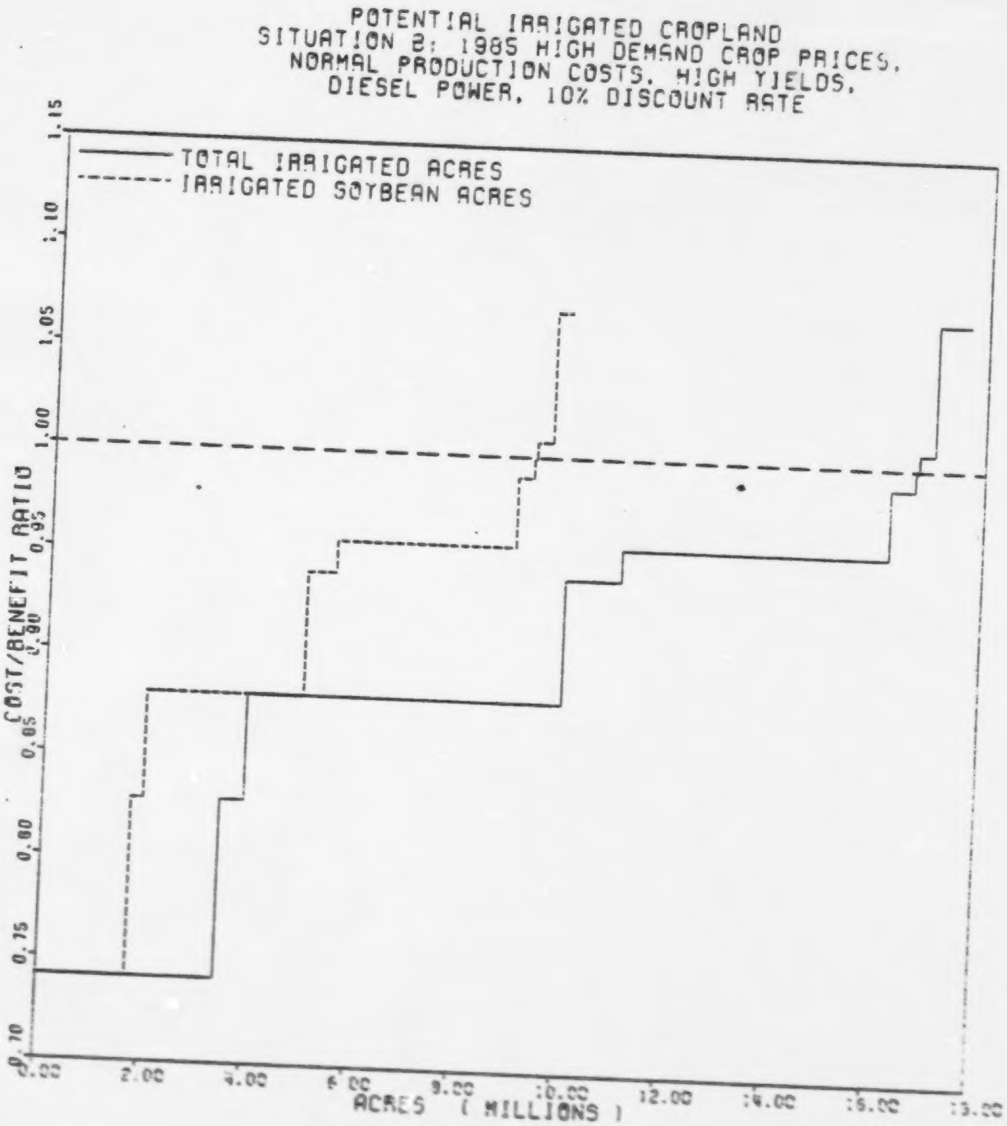
POTENTIAL IRRIGATED CROPLAND
SITUATION 2: 1985 HIGH DEMAND CROP PRICES.
NORMAL PRODUCTION COSTS. HIGH YIELDS.
DIESEL POWER. 10% DISCOUNT RATE
TOTAL IRRIGATED ACRES
IRRIGATED SOYBEAN ACRES
COST/BENEFIT RATIO
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
ACRES (MILLIONS)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00

Figure A-3

POTENTIAL IRRIGATED CROPLAND
SITUATION C: 1985 BASELINE CROP PRICES,
NORMAL PRODUCTION COSTS, HIGH YIELDS,
ELECTRIC POWER, 10% DISCOUNT RATE

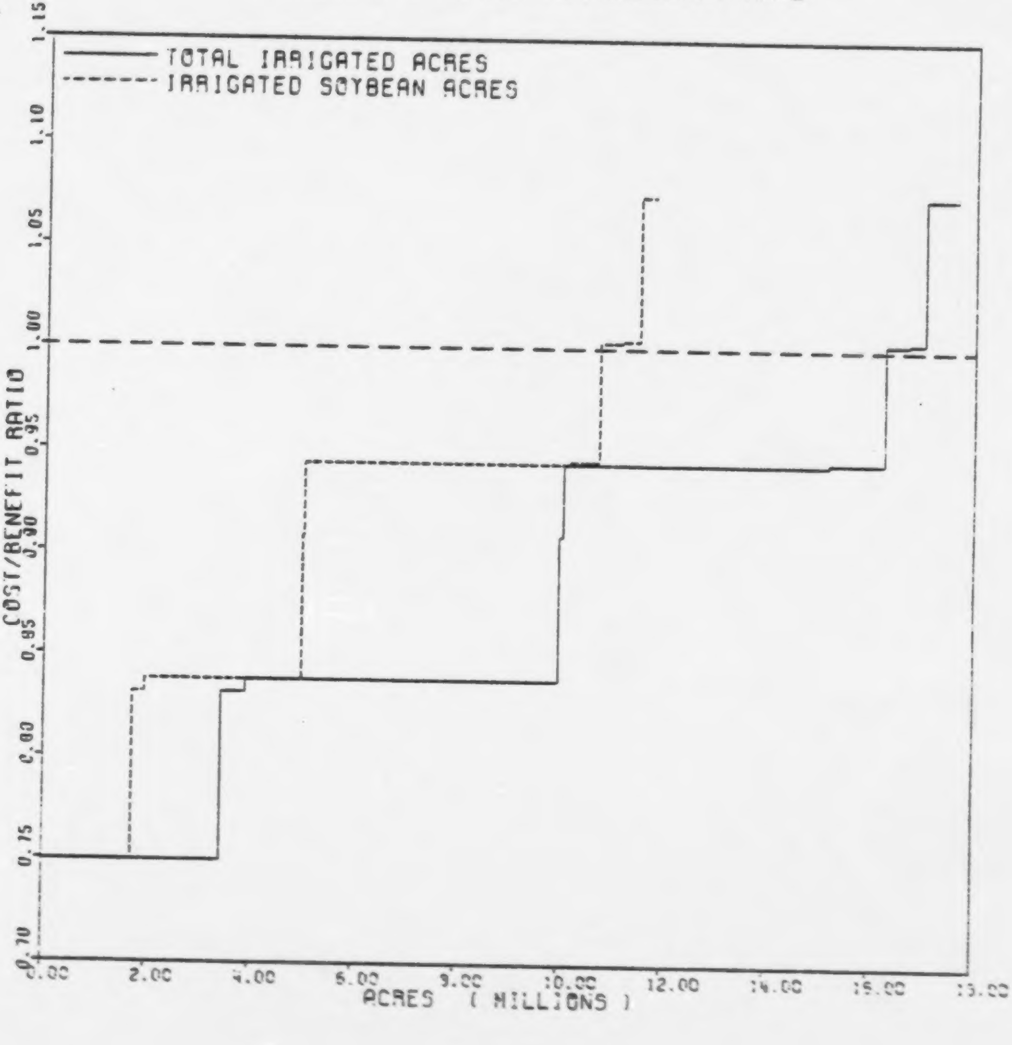

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Figure A-4

POTENTIAL IRRIGATED CROPLAND
SITUATION D; 1995 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, HIGH YIELDS,
ELECTRIC POWER, 10% DISCOUNT RATE

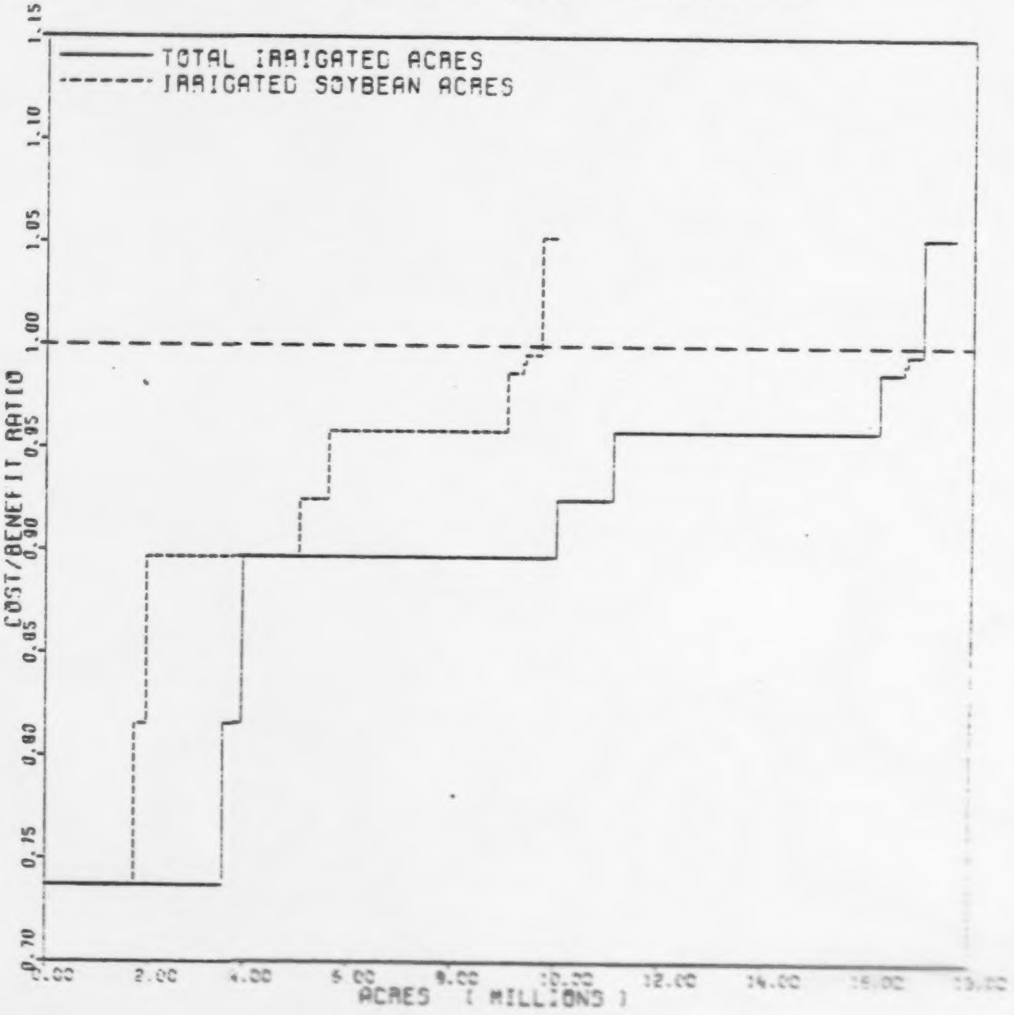

Figure A-5

POTENTIAL IRRIGATED CROPLAND
SITUATION E; 1985 BASELINE CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
DIESEL POWER, 10% DISCOUNT RATE

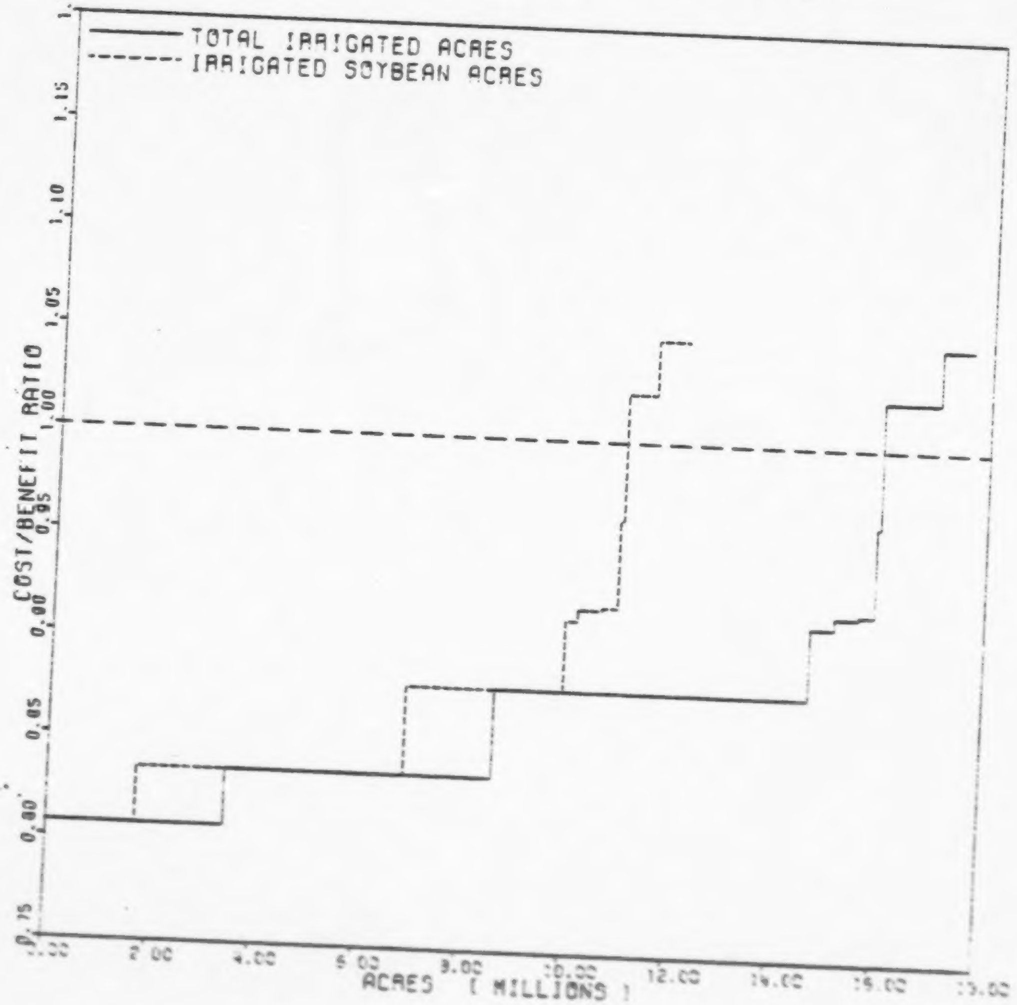

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Figure A-6

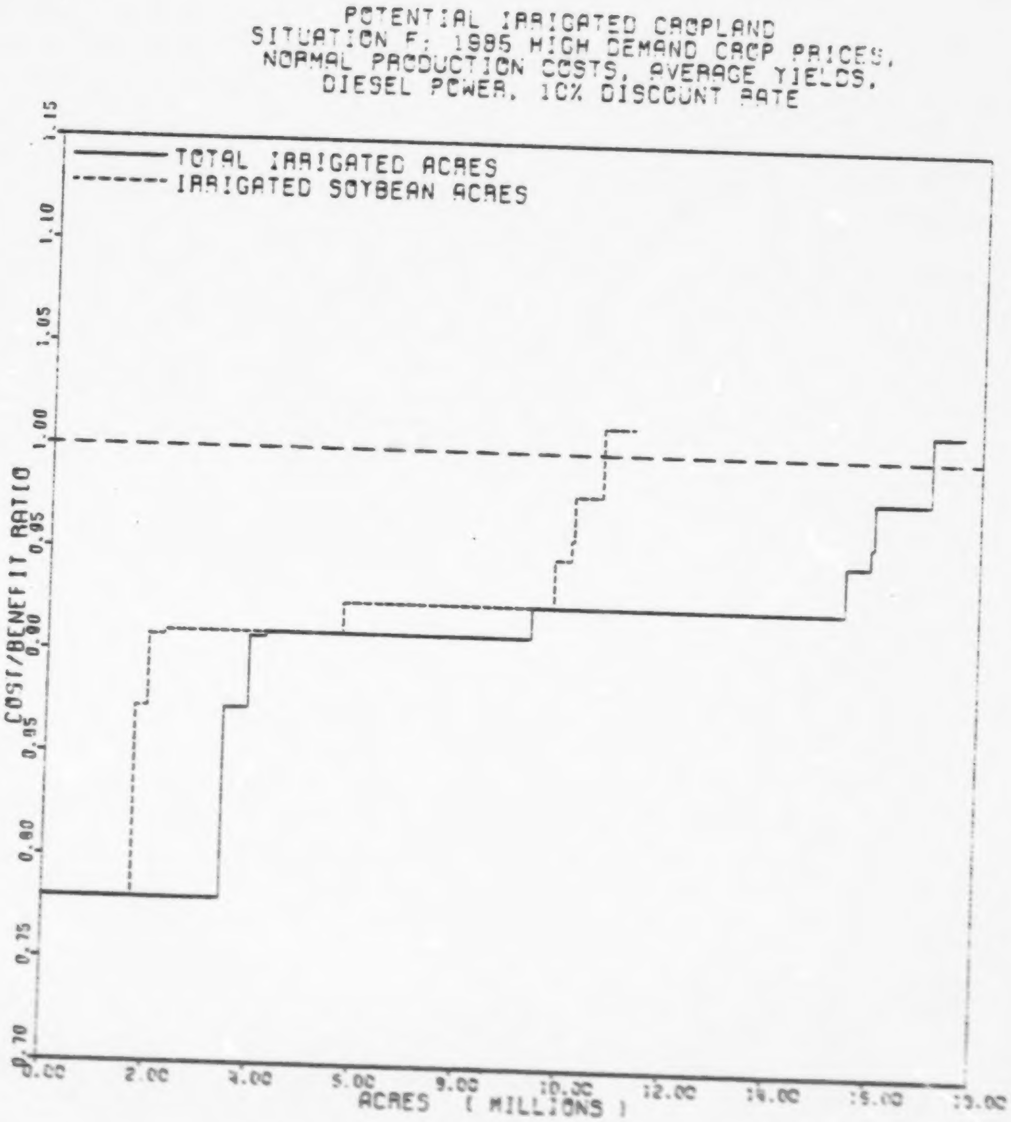
POTENTIAL IRRIGATED CROPLAND
SITUATION F: 1985 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
DIESEL POWER, 10% DISCOUNT RATE
TOTAL IRRIGATED ACRES
IRRIGATED SOYBEAN ACRES
COST/BENEFIT RATIO
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
ACRES (MILLIONS)

Figure A-7

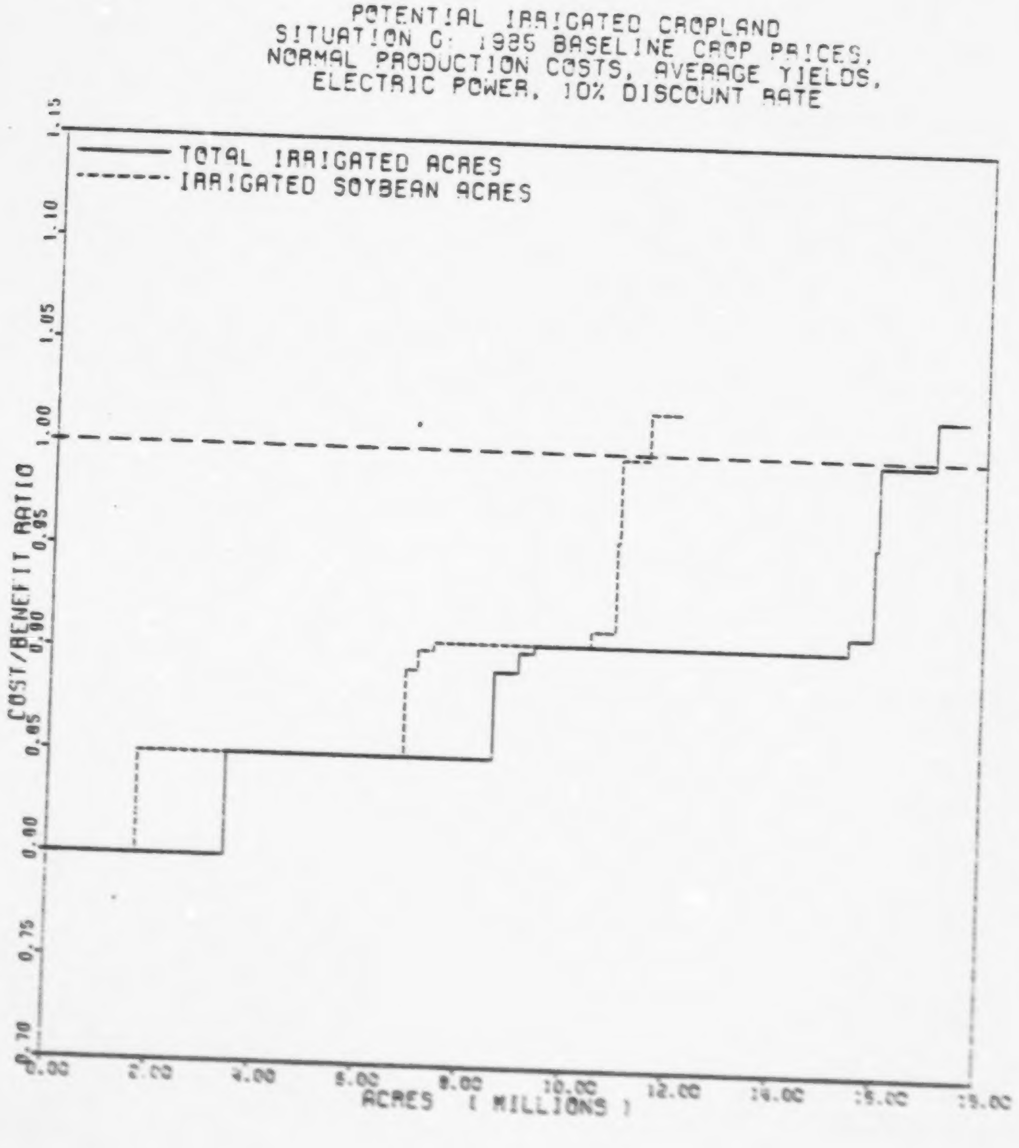
POTENTIAL IRRIGATED CROPLAND
SITUATION C: 1985 BASELINE CROP PRICES, NORMAL PRODUCTION COSTS, AVERAGE YIELDS, ELECTRIC POWER, 10% DISCOUNT RATE
TOTAL IRRIGATED ACRES
IRRIGATED SOYBEAN ACRES
COST/BENEFIT RATIO
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
ACRES (MILLIONS)

Figure A-8

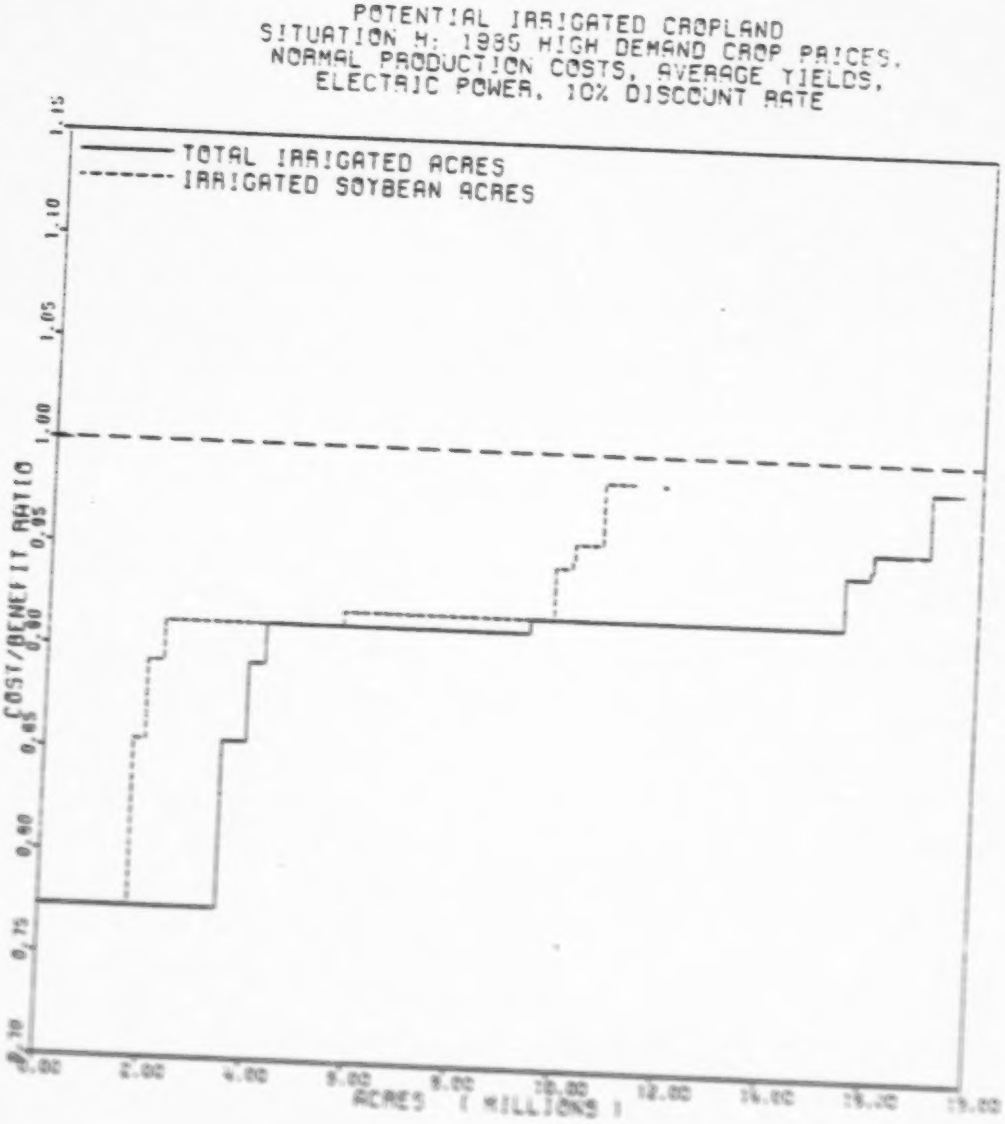

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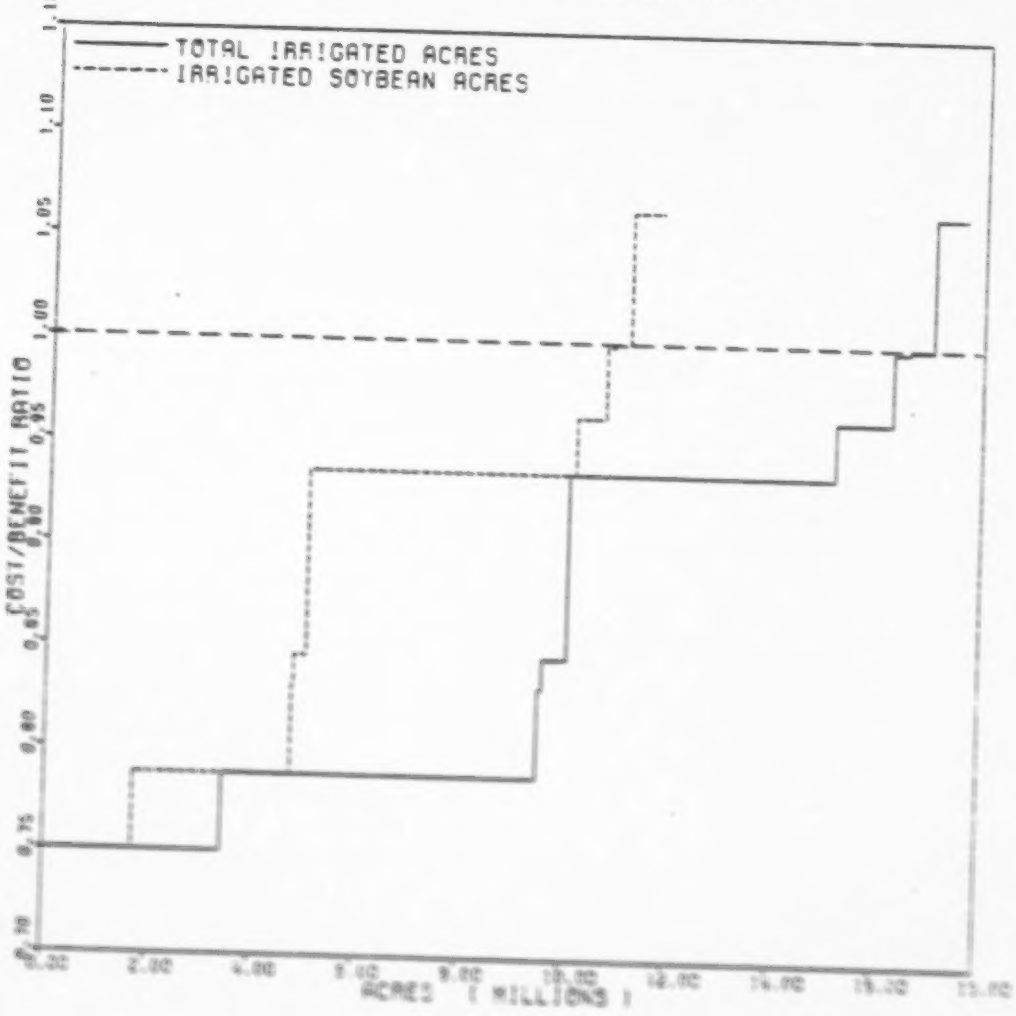
Figure A-9



POTENTIAL IRRIGATED CROPLAND
SITUATION I: 1985 BASELINE CROP PRICES,
NORMAL PRODUCTION COSTS, HIGH YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

Figure A-10

POTENTIAL IRRIGATED CROPLAND
SITUATION J: 1985 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, HIGH YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

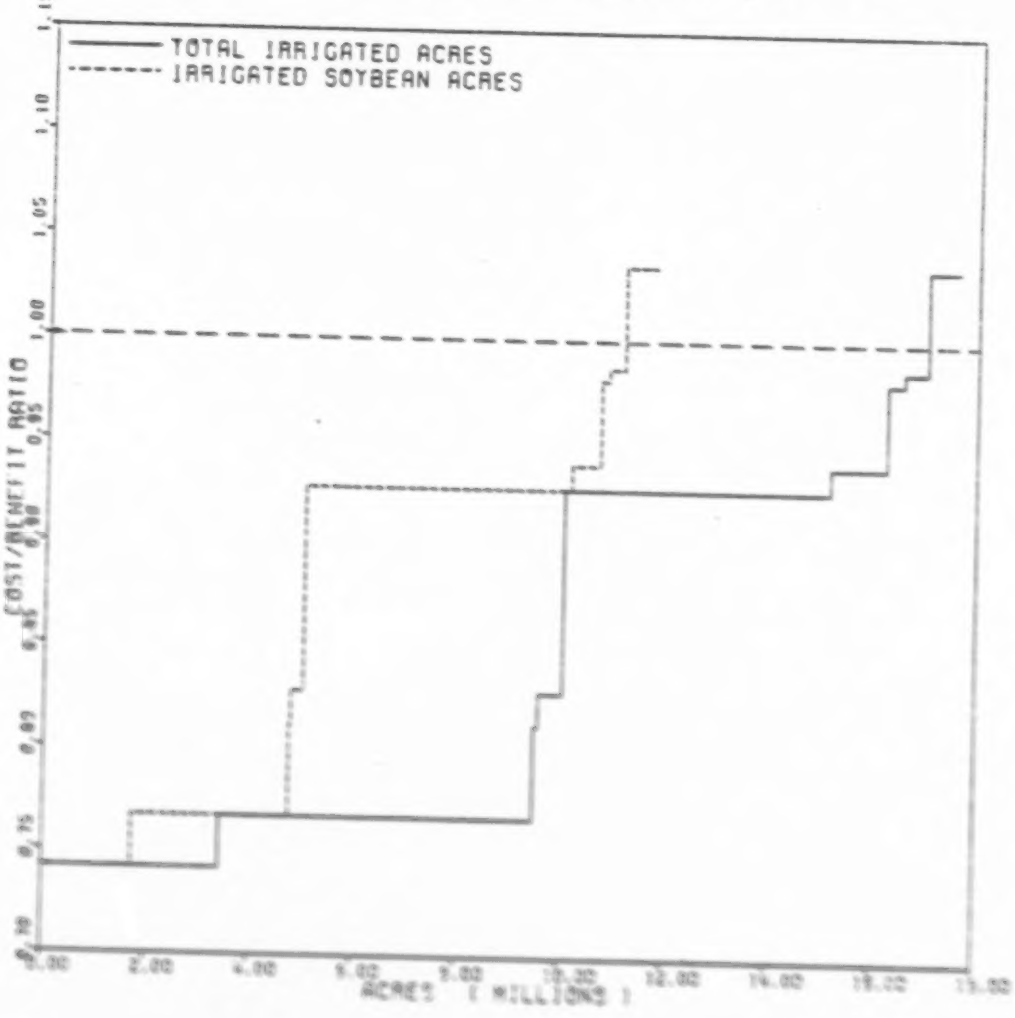
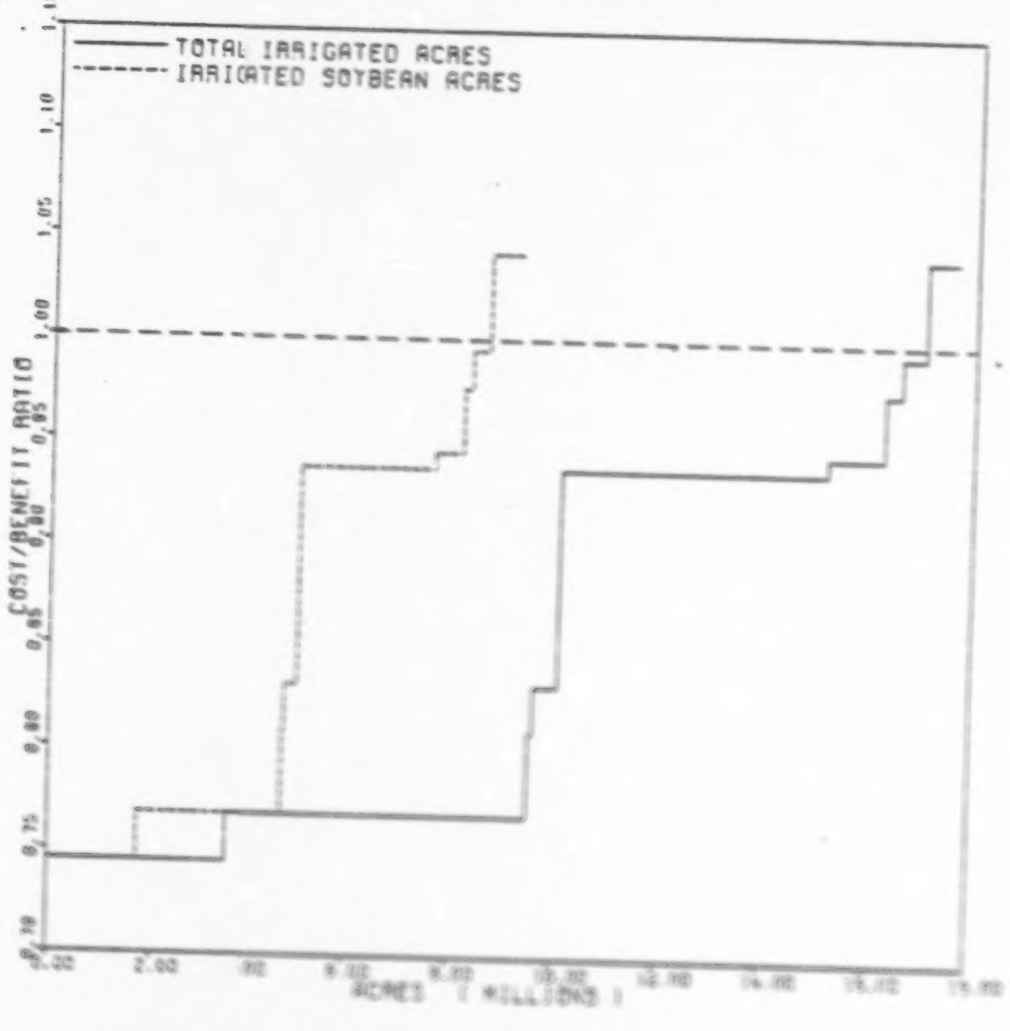


Figure A-11



POTENTIAL IRRIGATED CROPLAND
SITUATION K: 1995 BASELINE CROP PRICES.
NORMAL PRODUCTION COSTS, HIGH YIELDS.
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

Figure A-12

POTENTIAL IRRIGATED CROPLAND
SITUATION L: 1985 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, HIGH YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

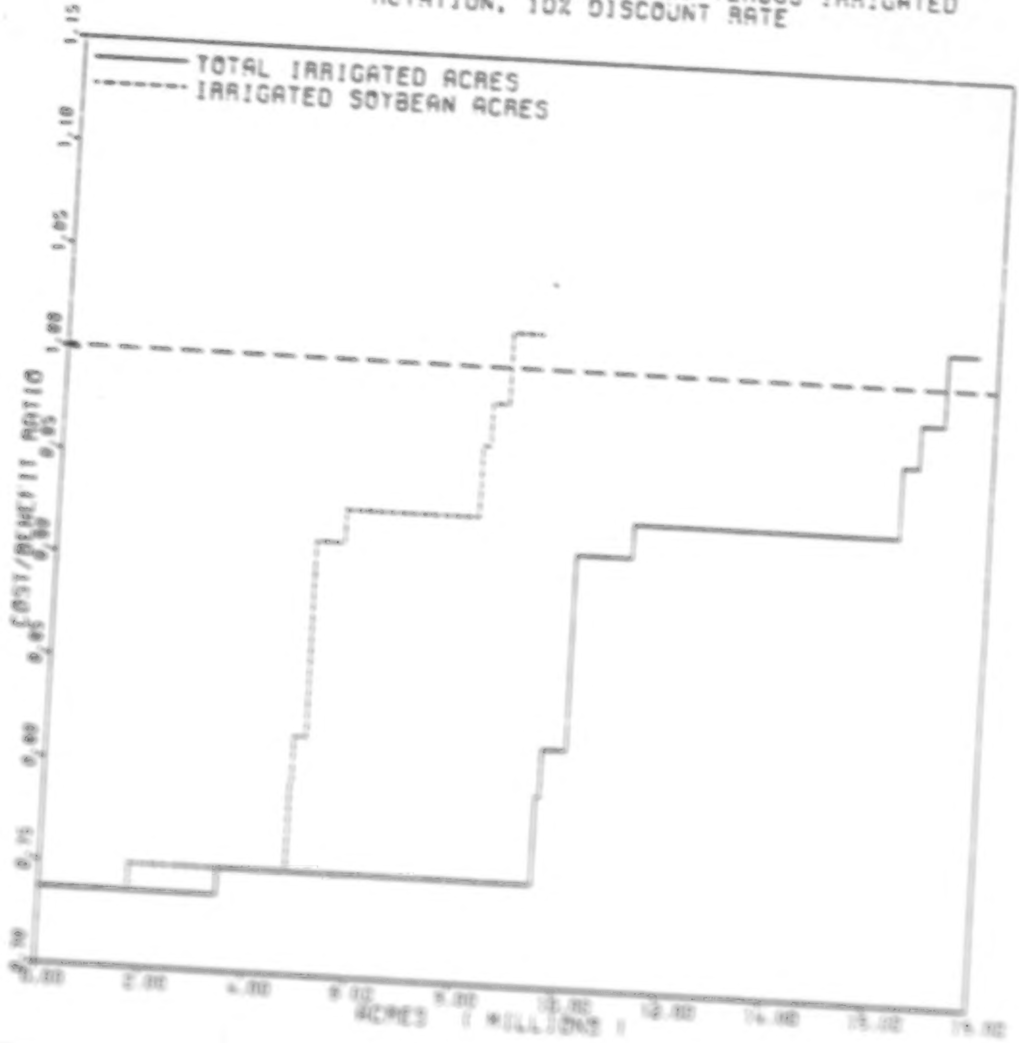


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Figure A-13

POTENTIAL IRRIGATED CROPLAND
SITUATION M: 1985 BASELINE CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

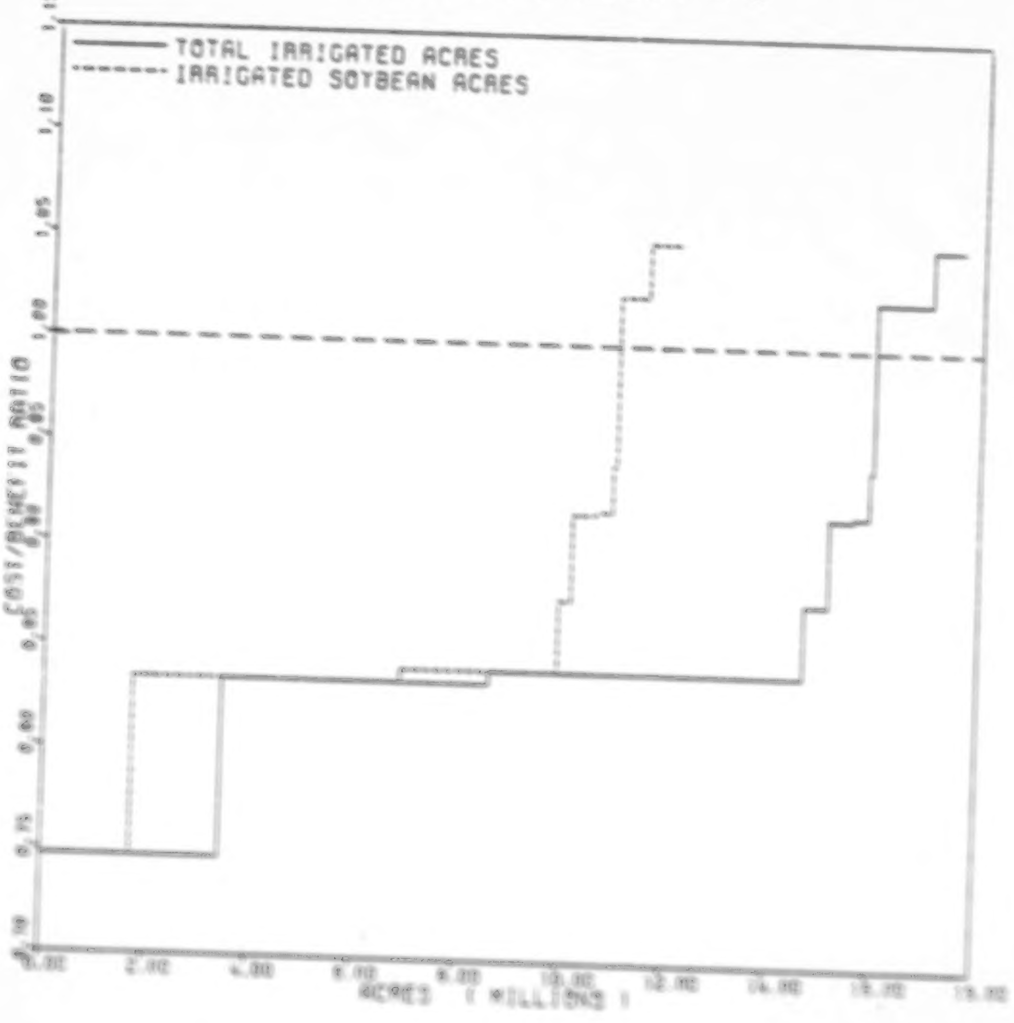

Figure A-14

POTENTIAL IRRIGATED CROPLAND
SITUATION K: 1985 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

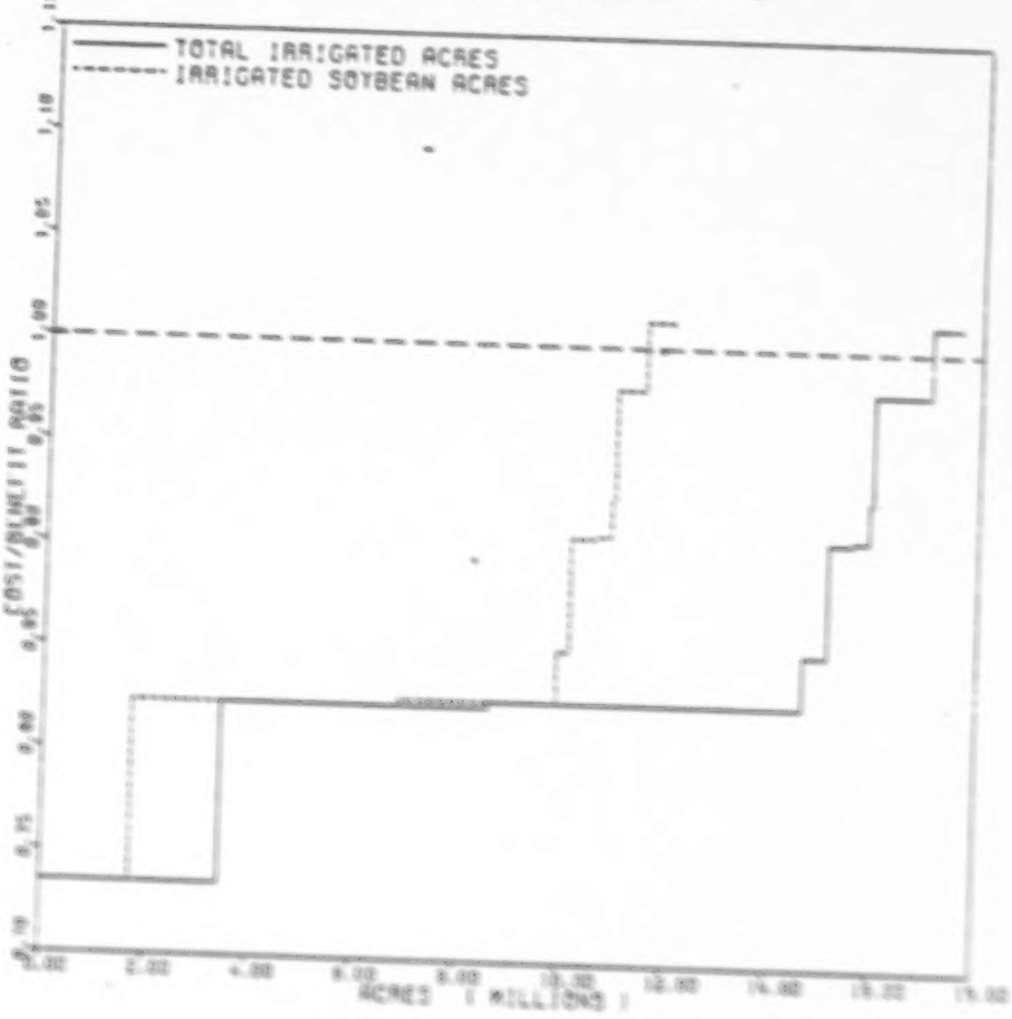

Figure A-15

POTENTIAL IRRIGATED CROPLAND
SITUATION 0; 1985 BASELINE CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

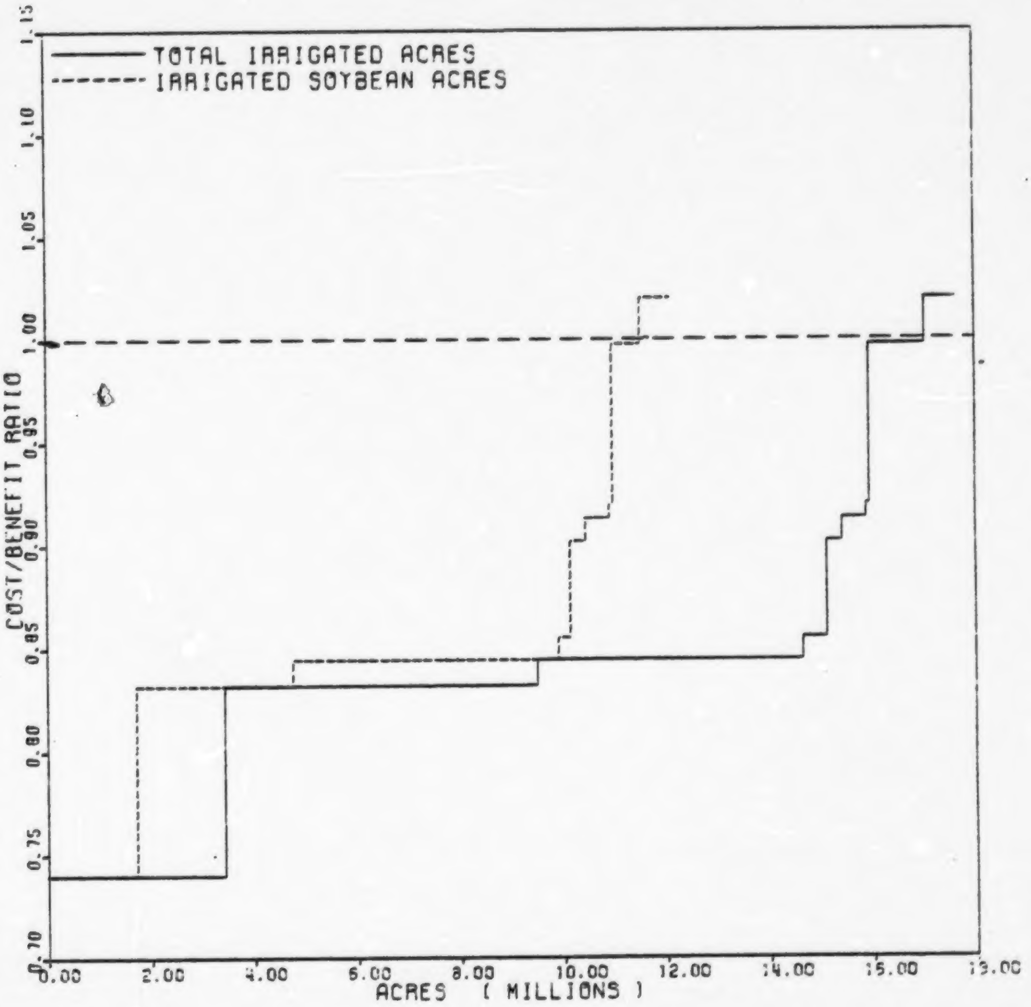

Figure A-16

POTENTIAL IRRIGATED CROPLAND
SITUATION P: 1985 HIGH DEMAND CROP PRICES,
NORMAL PRODUCTION COSTS, AVERAGE YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

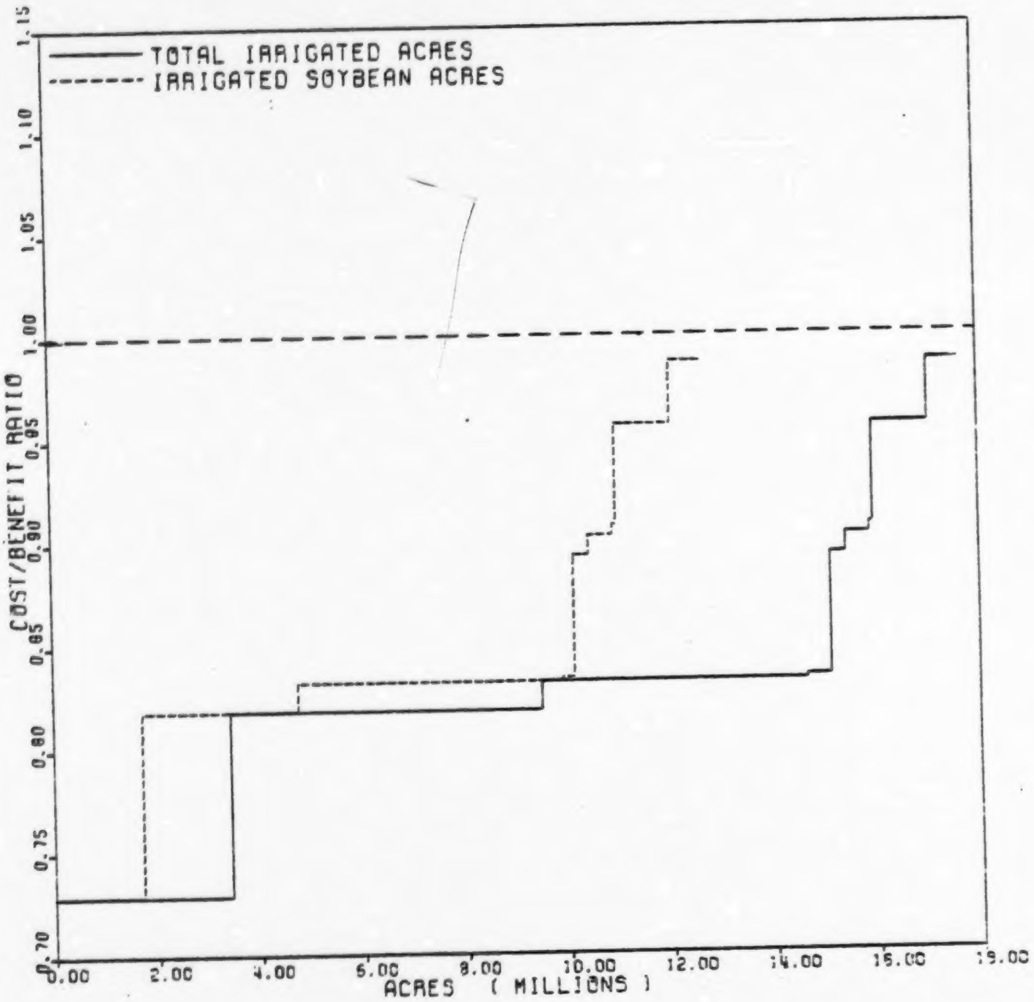

Figure A-17

POTENTIAL IRRIGATED CROPLAND
SITUATION Q: 1985 BASELINE CROP PRICES,
VARIABLE COSTS INCREASED 33%, HIGH YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

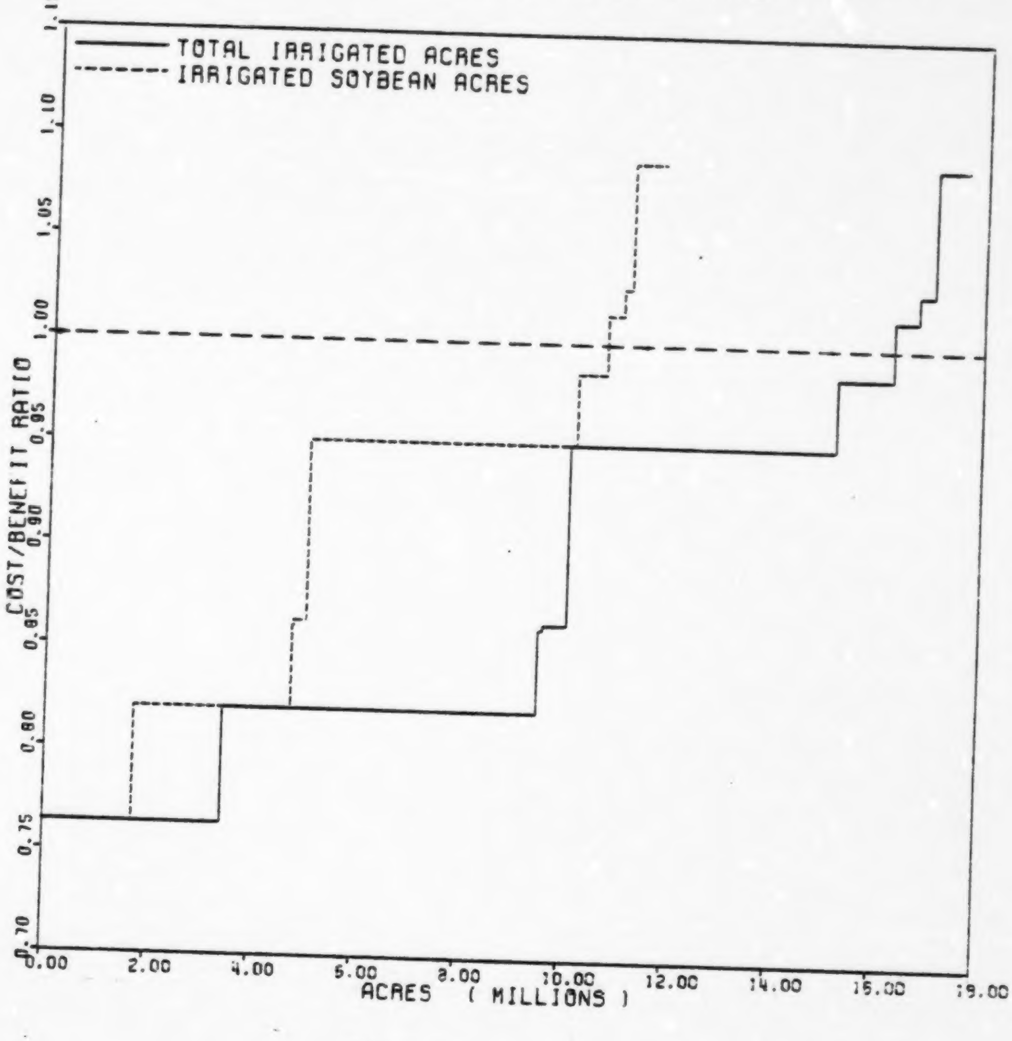

Figure A-18

POTENTIAL IRRIGATED CROPLAND
SITUATION 5: 1985 HIGH DEMAND CROP PRICES,
VARIABLE COSTS INCREASED 33%, HIGH YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

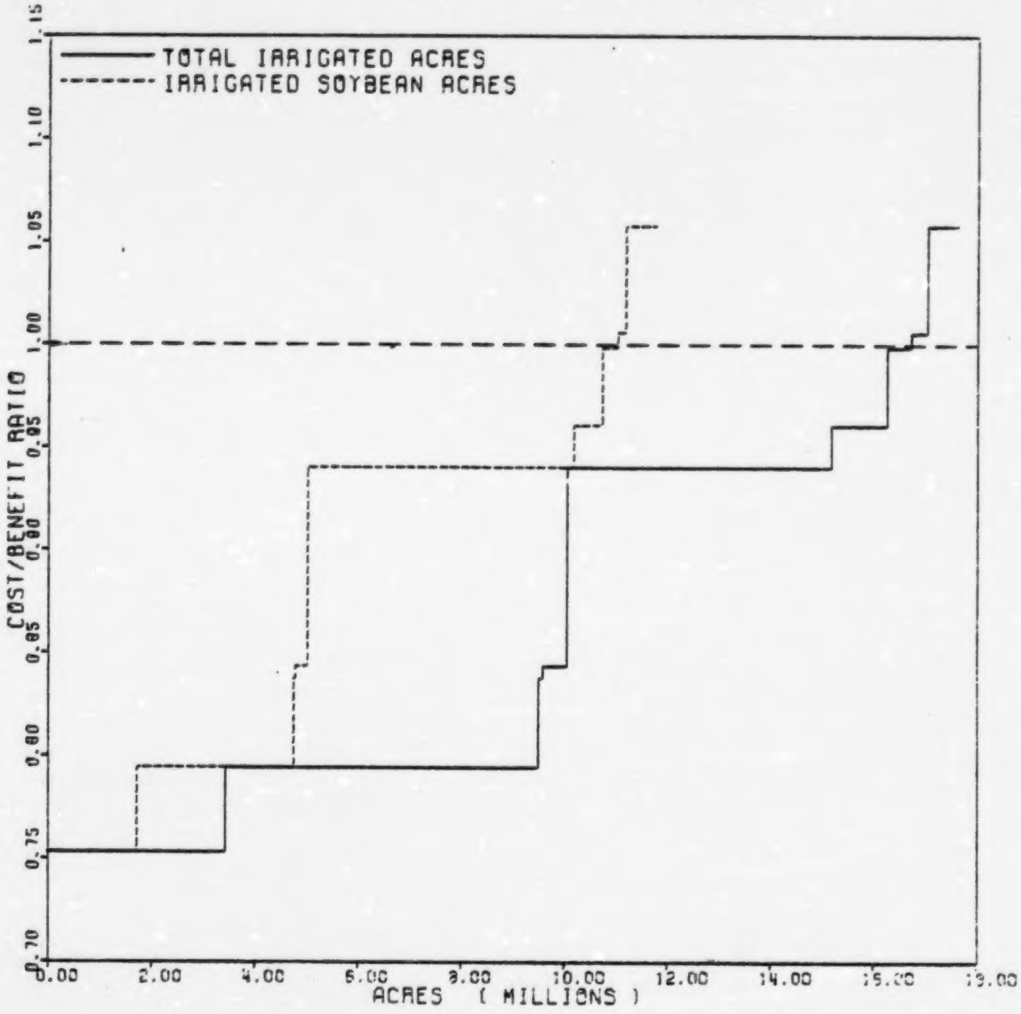

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Figure A-19

POTENTIAL IRRIGATED CROPLAND
SITUATION S; 1985 BASELINE CROP PRICES
VARIABLE COSTS INCREASED 33%, HIGH YIELDS, ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED ROTATION, 10% DISCOUNT RATE

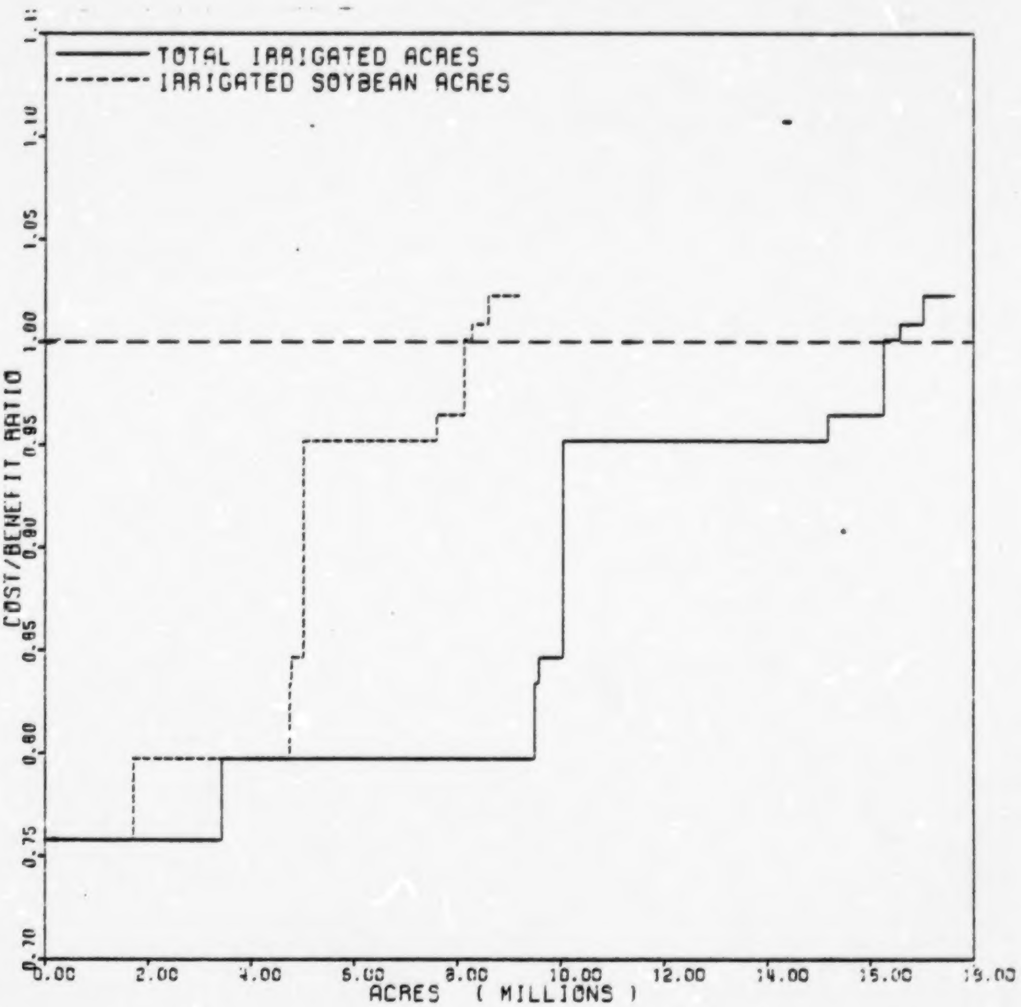
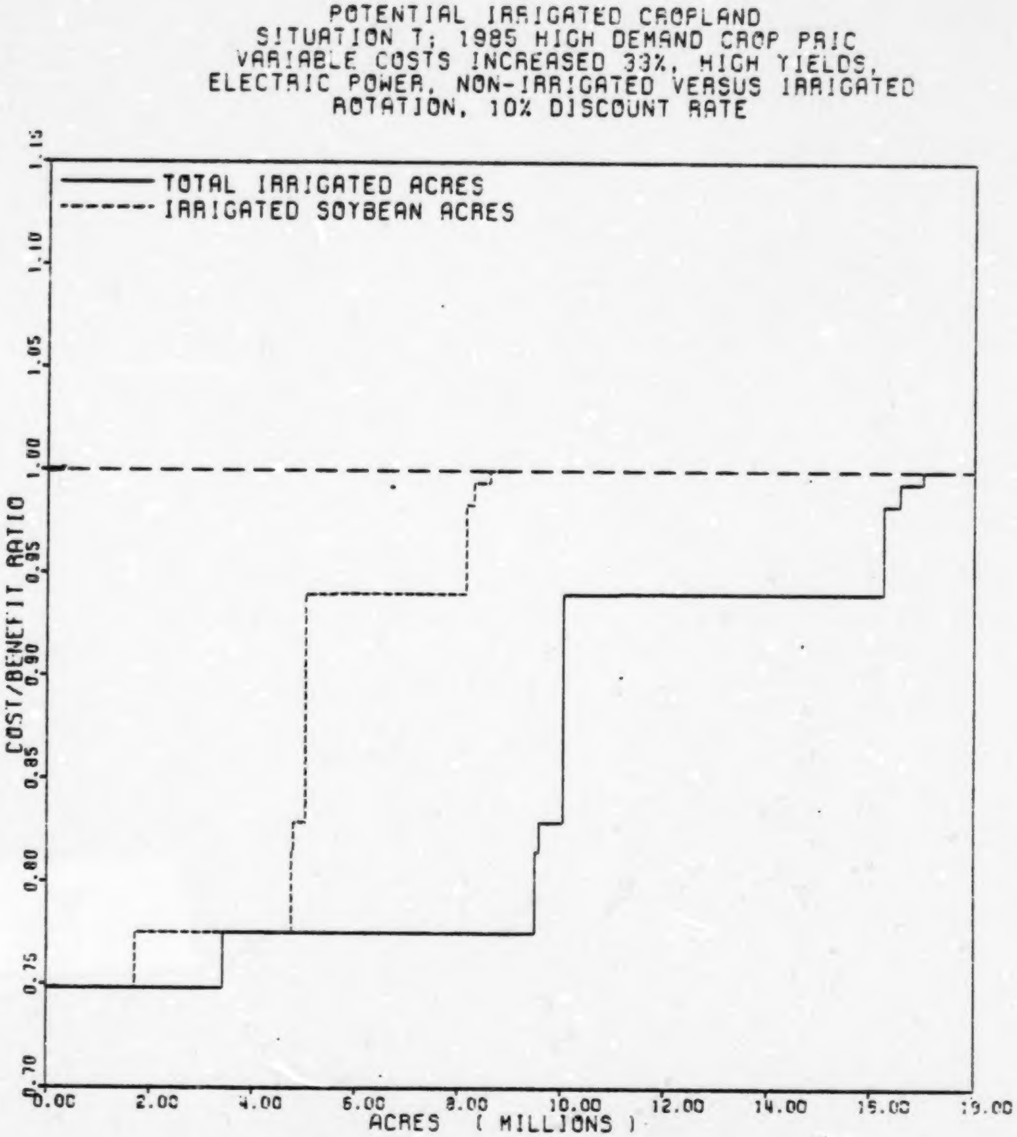


Figure A-20



POTENTIAL IRRIGATED CROPLAND
SITUATION T; 1985 HIGH DEMAND CROP PRIC
VARIABLE COSTS INCREASED 33%, HIGH YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

Figure A-21

POTENTIAL IRRIGATED CROPLAND
SITUATION U: 1985 BASELINE CROP PRICES,
VARIABLE COSTS INCREASED 33%, AVERAGE YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

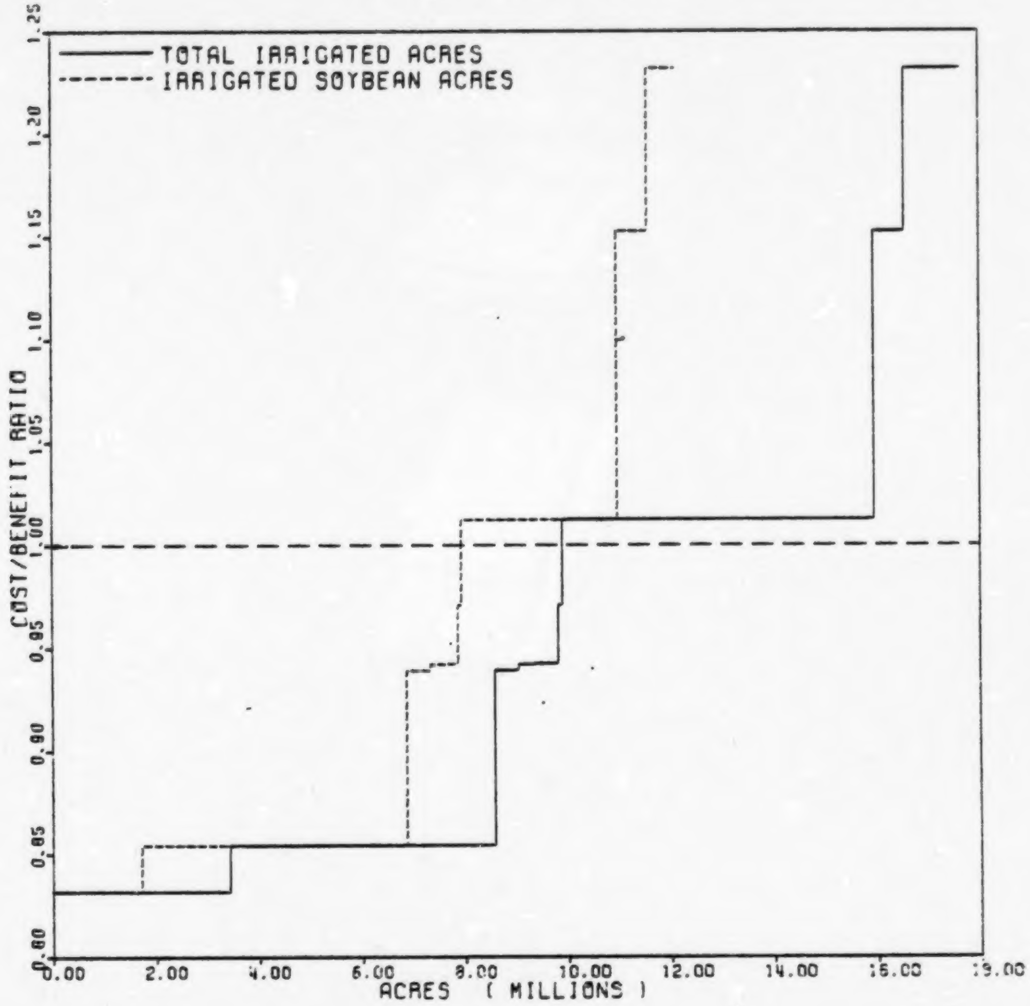


Figure A-22

POTENTIAL IRRIGATED CROPLAND
SITUATION V; 1985 HIGH DEMAND CROP PRICES,
VARIABLE COSTS INCREASED 33%, AVERAGE YIELDS,
DIESEL POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

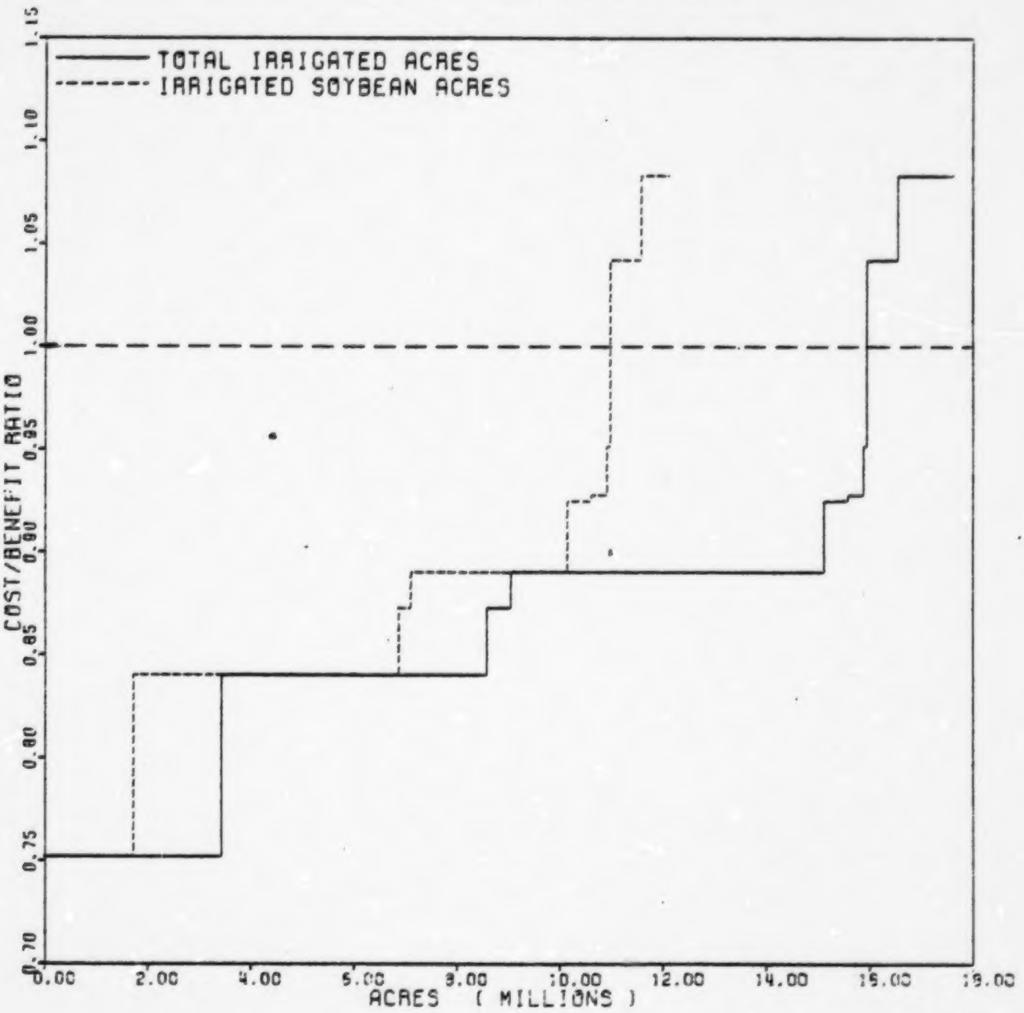


Figure A-23

POTENTIAL IRRIGATED CROPLAND
SITUATION W: 1985 BASELINE CROP PRICES,
VARIABLE COSTS INCREASED 33%, AVERAGE YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE

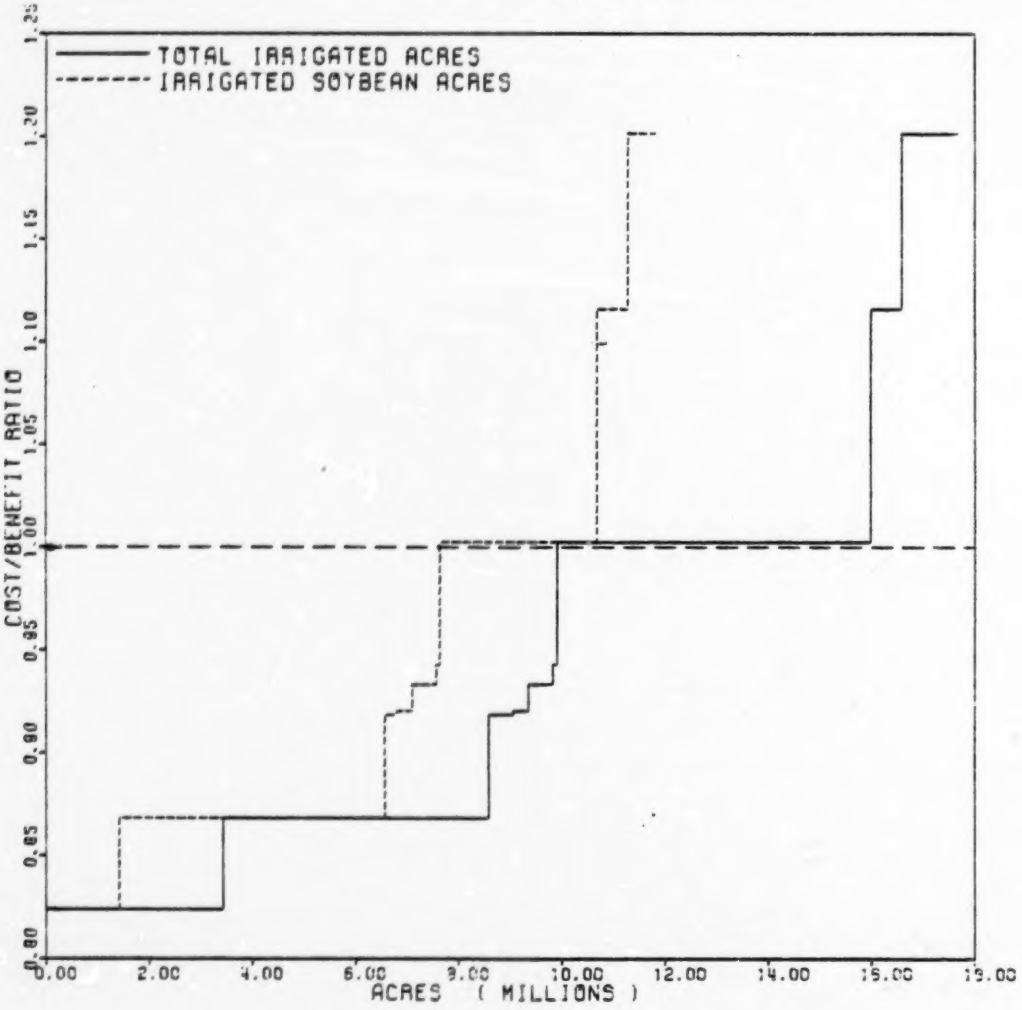
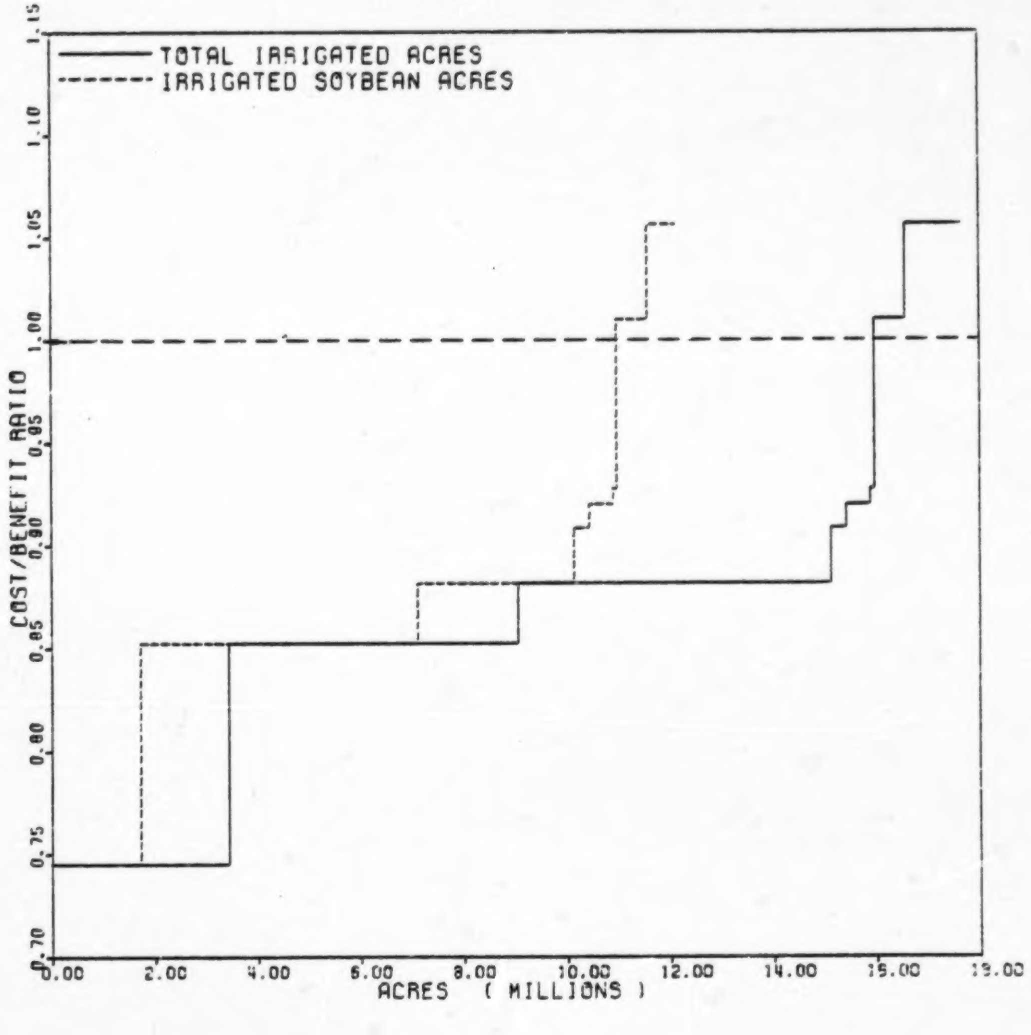


Figure A-24


POTENTIAL IRRIGATED CROPLAND
SITUATION X; 1985 HIGH DEMAND CROP PRICES,
VARIABLE COSTS INCREASED 33%, AVERAGE YIELDS,
ELECTRIC POWER, NON-IRRIGATED VERSUS IRRIGATED
ROTATION, 10% DISCOUNT RATE